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# **Military Engineering**

## **Volume V**

### **ROADS, AIRFIELDS, AND MECHANICAL EQUIPMENT**

#### **PART II**

## **AIRFIELDS**

(PROVISIONAL)

**1946**

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*By Command of the Army Council,*

General Headquarters

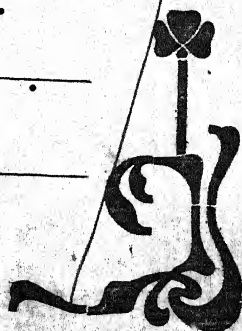
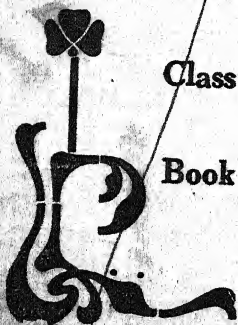


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## INTRODUCTION

This manual deals with all engineer services, peculiar to the R.A.F., for which the Army is responsible in any theatre of operations abroad. Recent changes of practice which have resulted from experience in the field, from co-ordination of British and American activities, and from research into new methods of construction have been included.

Principles and practice are covered broadly. Reference should be made to the following publications for amplification of special problems :—

Military Engineering, Vol. V, Part I, "Roads"—1944.

"Airfields," E.-in-C. India, Pamphlet No. 1, 1944.

"Aviation Engineers"—U.S.A. Technical Manual—TM5—255, April, 1944.

"Field Manual. Military Airdromes"—U.S.A. Services of Supply. S.W. Pacific—July, 1943.

"Aviation Engineer Notes." Air Engineer Headquarters, Washington, U.S.A.

"Landing Ground Manual." Air Ministry, 1939. ✓

Reports of Road Research Laboratory, England, 1939-1946.

"Rapid Construction of Airfields and Roads by the Hertzberg Process." E.-in-C. India, Pamphlet No. 12, 1944.

Military Engineering, Vol. VII, Part IX—Expeditionary Force ✓  
Depots.

Details of unit organization are given for the purpose of facilitating co-operation between British and American engineers in the field.

## GLOSSARY OF AIRFIELD TERMS

The terms used by British and American engineers, in connection with airfield construction in different theatres, have not yet been fully standardized. Even such fundamental terms as "runway" and "airfield" are used with different meanings. Definitions introduced in conflict with common usage have occasionally been confusing.

The following glossary is based largely upon technical reports in current official publications.

**Advanced landing grounds** are those which are prepared in operations for a tactical air force with or without a landing mat.

**Aerodrome or Airdrome.**—An all-weather airfield equipped with facilities for shelter, supply and maintenance of aircraft. The term is no longer authorized officially, but is still widely used in technical reports. "Airdrome" is frequently employed for "Airfield" in American publications.

**Air base (USA).**—An area command for supply and administra-

### Glossary of Airfield Terms—*continued.*

**Aircraft pen or revetment.**—A dispersal point protected from blast and splinters. Pens may be of "surface," "sunken" and "semi-sunken" types. The term "revetment" (U.S.A.) is sometimes used synonymously with "pen" for types involving the use of revetting materials.

**Airfield.**—A general term to cover all types of area developed for the accommodation, landing, and take-off of aircraft.

**Angle of glide.**—Slope of a line extending upward and outward from the ends of strips, above which no obstruction should extend within the area of the approach funnel or zone.

**Approach funnel** (American—approach zone).—A trapezoidal area extending from the over-runs at each end of the flight strip, cleared of all flying obstacles above a specified glide angle. In India the term "flying gap" is used.

**Apron.**—A surfaced area for parking aircraft near hangars or control points.

**Cleared strip** (American—safety clearance zone).—An area cleared of all ground obstructions above a specified height along each side of the flight strip, to minimize accidents on operational fields where the provision of adequate width of graded and compacted shoulders is not possible.

**Dispersal or parking area.**—An area selected for the parking of aircraft at dispersed hardstandings, surfaced or natural. Generally served by dispersal lanes or branch taxi-tracks from the main taxi-track.

**Dropping zone.**—An area in which parachute troops or supplies are dropped.

**Emergency landing strip.**—A marked rectangular area naturally suitable or made suitable for the landing of aircraft in emergency. These are normally from 500–600 yards long by 50 yards wide. Name changed from "Crash landing strip," which was often inappropriate. Also provided alongside main runways to prevent damage to mat by landing of damaged aircraft.

**Flight strip or flying strip** (American—landing strip).—Includes the area of the runway or landing lane, shoulders, and over-run. Used to designate the area before and after runway or landing lane is surfaced. In India the term "arm" is used to designate this part of an airfield.

**Flightway.**—A term commonly used to describe a flight strip together with the two approach funnels.

**Hangarrette** (India).—Lightly roofed hangars of not more than 70

### Glossary of Airfield Terms—*continued.*

**Landing ground.**—A marked and prepared landing area with dispersal facilities, but without significant installations or accommodation.

**Landing run.**—The distance travelled by an aircraft in contact with the ground when landing.

**Landing zone.**—A naturally favourable area in which aircraft or gliders are landed in an airborne operation.

**Layback (India).**—A satellite in rear of an operational area for use upon withdrawal.

**Marshalling or assembly area.**—A surfaced area for the assembly or warming up of aircraft, at each end of runway or landing lane.

**Over-run (American—clear zone or end zone).**—An area graded and compacted in extension of the runway or landing lane and shoulders, to minimize risk of accident to aircraft due to over-run or premature touch down.

**Refuelling and re-arming strip.**—A marked rectangular landing area, hastily constructed in the forward area, for refuelling and re-arming during the critical phases of an offensive.

**Runway or landing lane.**—A prepared rectangular strip, of permanent or semi-permanent construction. The term runway is commonly used to designate an all-weather surface, and landing lane to designate a surface protected by a landing mat.

**Satellite or auxiliary airfield.**—A landing ground, of subsidiary or alternative use, dependent upon a neighbouring major airfield for administrative control.

**Shoulder.**—A graded and compacted area on either side of the runway or landing lane to minimize risk of accident to aircraft running off or landing off those areas.

**Staging post.**—An airfield with refuelling and accommodation facilities (personnel and stores), for aircraft on established communication routes.

**Take-off run.**—The distance travelled by an aircraft in contact with the ground before becoming airborne.

**Taxi-track or taxi-way (U.S.A.).**—A prepared natural or artificial track on which aircraft can taxi or be towed between runway and dispersal points. (Aircraft are said to taxi when moving along the ground under their own power.)

**Turning circle.**—A surfaced area at the ends of a runway to facilitate

# ABBREVIATIONS

Officers engaged upon engineer duties for the R.A.F. may require to be familiar with a wide range of administrative designations, special to the Service. The following list serves the dual purpose of recording correct Air Force designations and their standard abbreviations.

The use of abbreviations, other than the most familiar, is to be discouraged in inter-service reports and communications, especially when British and American forces are working in close liaison.

Inclusion in the list does not mean that an abbreviation is authorized for formal official use. Many are given to ensure correct interpretation by Engineer officers, when the abbreviations are used by Air Force personnel particularly concerned in the various activities covered.

## Airfields, aircraft and technical

Advanced landing ground	...	...	...	...	A.L.G.
Air sea rescue base	...	...	...	...	A.S.R.B.
Aircraft	...	...	...	...	a/c
Airfield	...	...	...	...	Airfd.
Air observation post	...	...	...	...	Air O.P.
All-weather (landing ground)	...	...	...	...	A.W.
Anti-surface vessel	...	...	...	...	A.S.V.
Base landing ground	...	...	...	...	B.L.G.
Bomber reconnaissance	...	...	...	...	B.R.
Direction finding	...	...	...	...	D.F.
Emergency landing strip	...	...	...	...	E.L.S.
Fair weather (landing ground)	...	...	...	...	F.W.
Fighter bomber	...	...	...	...	F.B.
Fighter reconnaissance	...	...	...	...	F.R.
Fuelling landing ground (old)	...	...	...	...	F.L.G.
Fighter director post	...	...	...	...	F.D.P.
General reconnaissance	...	...	...	...	gen. R.
Ground control interception	...	...	...	...	G.C.I.
Group control centre	...	...	...	...	G.C.C.
Hard standing	...	...	...	...	H.S.
Heavy bomber	...	...	...	...	H.B.
Landing zone (airborne operations)	...	...	...	...	L.Z.
Landing ground	...	...	...	...	L.G.
Light bomber	...	...	...	...	L.B.
Light warning set	...	...	...	...	L.W.S.
Long range fighter	...	...	...	...	L.R.F.
Mean point of impact	...	...	...	...	M.P.I.
Medium bomber	...	...	...	...	M.B.
Night fighter	...	...	...	...	N.F.
Operational landing ground	...	...	...	...	O.L.G.
Radio telephony	...	...	...	...	R.T.
Refuelling and rearming strip	...	...	...	...	R.R.S.
Single engine fighter	...	...	...	...	S.E.F.
Standard beam approach	...	...	...	...	S.B.A.
Strategical reconnaissance	...	...	...	...	strat. R.
Tactical reconnaissance	...	...	...	...	tac. R.
Torpedo bomber	...	...	...	...	T.B.
Twin engine fighter	...	...	...	...	T.E.F.
Wind direction	...	...	...	...	W.D.
Wireless telegraphy	...	...	...	...	W.T.

Administrative staff	...	...	...	Adm.
Advanced repair unit	...	...	...	A.R.U.
Advanced aircraft depot	...	...	...	A.A.D.
Aeronautical inspection depot	...	...	...	A.I.D.*
Air ammunition park	...	...	...	A.A.P.
Air Force reinforcing route control	...	...	...	A.R.R.C.
Air formation signals...	...	...	...	A.F.S.
Air despatch and reception unit	...	...	...	A.D.R.U.
Air Ministry experimental station	...	...	...	A.M.E.S.
Air Ministry works directorate	...	...	...	A.M.W.D.
Air observation post squadron	...	...	...	A.O.P. Sqn.
Air sea rescue service	...	...	...	A.S.R.S.
Air staff	...	...	...	A.S.
Air stores park	...	...	...	A.S.P.
Aircraft delivery unit	...	...	...	A.D.U.
Aircraft equipment depot	...	...	...	A.E.D.
Aircraft erection unit	...	...	...	A.E.U.
Aircraft repair section	...	...	...	A.R.S.
Aircraft replacement pool	...	...	...	A.R.P.
Aircraft storage unit	...	...	...	A.S.U.
Airfield construction group	...	...	...	Airfd. Constr. Gp.
Communication flight	...	...	...	comm. ft.
Component repair section	...	...	...	C.R.S.
Decoy and deception section	...	...	...	D. and D.S.
Embarkation unit	...	...	...	E.U.
Engine repair section	...	...	...	E.R.S.
Equipment and storage unit	...	...	...	E. and S.U.
Ferry control	...	...	...	F.C.
Flight	...	...	...	ft.
Flying control station	...	...	...	F.C.S.
Forward director post	...	...	...	F.D.P.
General reconnaissance unit	...	...	...	G.R.U.
Group	...	...	...	gp.
Group control centre	...	...	...	Gp. C.C.
Instrument repair section	...	...	...	I.R.S.
Initial equipment (1st line a/c strength)...	...	...	...	I.E.
Immediate reserve (a/c immediately available)	...	...	...	I.R.
Maintenance unit	...	...	...	M.U.
Mechanical transport light repair unit	...	...	...	M.T.L.R.U.
Meteorological establishments	...	...	...	met.
Meteorological flight	...	...	...	Met. ft.
Mobile air reporting unit	...	...	...	M.A.R.U.
Mobile field photographic section	...	...	...	M.F.P.S.
Mobile operations room unit	...	...	...	M.O.R.U.
Mobile signals unit	...	...	...	M.S.U.
Operational training unit	...	...	...	O.T.U.
Organization branch (ground duties)	...	...	...	org.
Photographic reconnaissance unit	...	...	...	P.R.U.
Radio direction finding unit	...	...	...	R.D.F.U.
Radio and Installation maintenance unit	...	...	...	R.I.M.U.
Refuelling and rearming party	...	...	...	R. and R. Party
Repair and salvage unit	...	...	...	R.S.U.
Sea rescue flight	...	...	...	S.R.F.
Squadron	...	...	...	sqn.
Strategical air force	...	...	...	S.A.F.
Strategical recce. flight	...	...	...	strat. R. ft.
Sector filter room	...	...	...	S.F.R.

Tactical air force	...	...	...	...	T.A.F.
Torpedo bomber squadron	...	...	...	...	T.B. sqn.
Wing	...	...	...	...	wg.
Wireless observer unit	...	...	...	...	W.O.U.
Wireless unit post	...	...	...	...	W.U. Post.

### Admiralty

Director aircraft and carrier requirements	...	D.A.C.R.
Fleet Air Arm...	...	F.A.A.
Mobile naval airfield unit (Royal Marines)	...	M.N.A.F.

### R.A.F. appointments and commands

Air chief marshal	...	A.C.M.
Air commodore	...	A/Cdre.
Air marshal	...	A.M.
Air officer commanding	...	A.O.C.
Air officer I.C. administration	...	A.O.A.
Air liaison officer	...	A.L.O.
Air vice marshal	...	A.V.M.
Anti-aircraft defence commander	...	A.A.D.C.
Chief airfield control officer	...	C.A.C.O.
Chief cypher officer	...	C. Cy. O.
Chief maintenance and supply officer	...	C.M.S.O.
Chief meteorological officer	...	C. Met. O.
Chief radio officer	...	C.R.O.
Command armament officer	...	C.A.O.
Command defence officer	...	C.D.O.
Command navigation officer	...	C. Nav. O.
Command photographic officer	...	C. Ph. O.
Command signals officer	...	C.S.O.
Flight lieutenant	...	F/Lt.
Flying officer	...	F.O.
Group captain	...	G/Capt.
Principal medical officer	...	P.M.O.
Pilot officer	...	P.O.
Senior administration plans staff officer	...	S.A.P.S.O.
Senior air staff officer	...	S.A.S.O.
Senior equipment staff officer	...	S.E.S.O.
Senior intelligence staff officer	...	S.I.S.O.
Senior operations staff officer	...	S.O.S.O.
Senior organization and administration officer	...	S.O.A.O.
Senior organization officer	...	Org. I.
Senior personnel staff officer	...	S.P.S.O.
Senior repair and servicing officer	...	S.R.S.O.
Senior training staff officer	...	S.T.S.O.
Staff officer I.C. administration	...	S.O.A.
Squadron leader	...	S./Ldr.
Wireless units liaison officer	...	W.U.L.O.
Wing commander	...	W./Cdr.

### AMERICAN—MISCELLANEOUS

Corps of engineers	...	C.E.
Aviation engineers	...	Avn. Engrs.
Air Corps	...	A.C.
Service of Supply	...	S.O.S.
Table of Organization (W.E.)	...	T/O
Table of Equipment (G1098)	...	T/E
Enlisted men (O.Rs.)	...	E.M.
Training Manual	...	

# MILITARY ENGINEERING

## Volume V

### ROADS, AIRFIELDS, AND MECHANICAL EQUIPMENT

## PART II—AIRFIELDS

### CHAPTER 1

#### AIRFIELD STANDARDS

##### SECTION 1.—GENERAL

1. Standardization of airfield layout and designs, for universal application, is not practicable or desirable. Standards are laid down by the appropriate Air Command to suit, tactically and technically, the area and situation concerned. These standards may vary widely. For instance, landing lanes, 1,200 by 30 yards, off-wind, have been accepted as minimum operational standards for day fighters during one campaign, whilst 1,500 yard squares have been provided, coincidentally, during another, under favourable desert conditions. Standards will also be changed, from time to time, owing to the introduction of larger or faster aircraft types and to the varying measure of air superiority.

It is nevertheless agreed that the utmost uniformity of practice should prevail and that divergencies from basic standards should be due to clearly expressed causes, and be approved by Commands.

Demands in general have become gradually more exacting. Calls for maximum speed of work and transportation difficulties necessitate the closest economy, in layout and methods of construction, compatible with safety.

2. Standard types given or discussed below are for Engineer guidance, but will not necessarily apply to any particular theatre or operations. They may be used for reconnaissance purposes, failing the explicit instructions from Air Commands which generally precede or coincide with the start of work.

##### SECTION 2.—DISTANCES APART OF AIRFIELDS

Attempts to establish a standard minimum distance apart (*e.g.*, 5 miles for T.A.F. airfields), to ensure safety in the air, have generally failed under operational conditions. Grouping is essential for administrative efficiency, and is commonly governed by topographical conditions. The question is a difficult one, calling for the frequent attention of Air Commands.

##### SECTION 3.—RUNWAY OR STRIP DESIGNATION

1. The simplest standard for runway designation is by numbers, in order of construction, and therefore presumably of importance. No. 1 Runway will also commonly be termed the "MAIN".

2. In giving bearings, the quadrants from 180 degrees to 360 degrees should invariably be used, for reliability of record and communication.

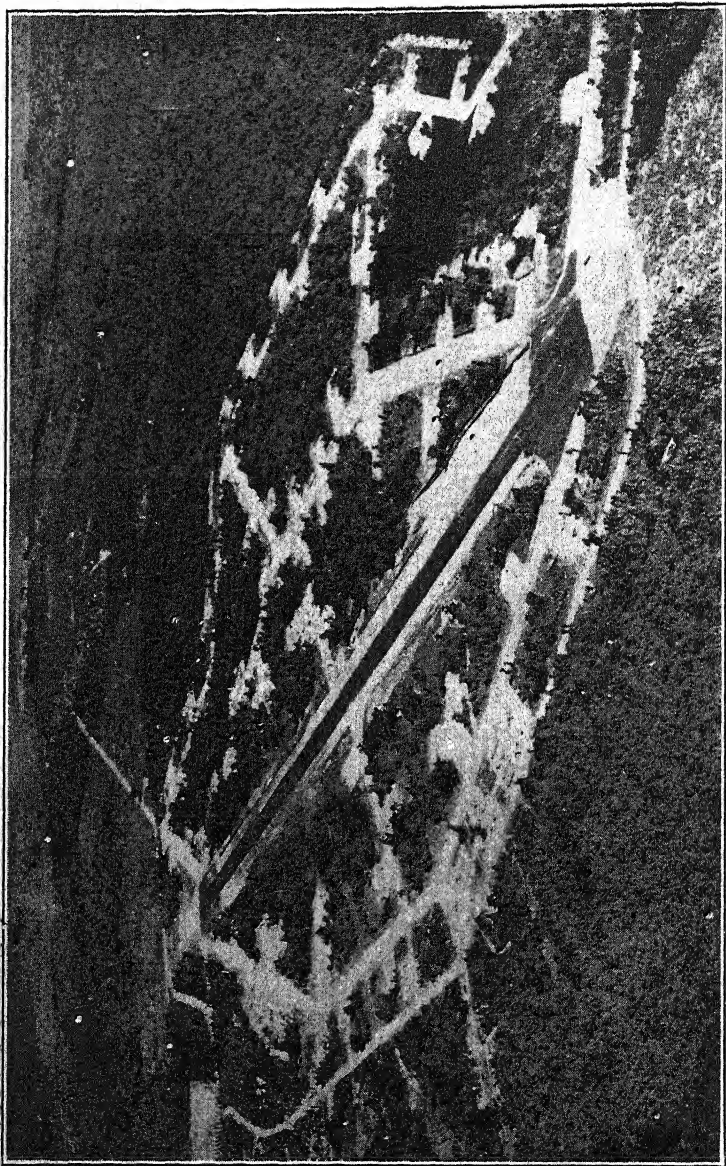


PLATE 1.—BOMBER AIRFIELD, SOUTHERN PACIFIC—BITUMEN RUNWAY ON CORAL FORMATION

1. **Dimensions.**—Dimensions of runway or landing lane for fighters, fighter bombers, and light bombers.

Minimum	...	...	...	...	1,200 × 30 yards
Standard	...	...	...	...	1,500 × 50 yards

Medium, and heavy bombers.

Minimum	(prevalent wind and calm)	1,750 × 50 yards
	(secondary—)	1,500 × 50 yards
Standard	(prevalent wind and calm)	2,000 × 50 yards
	(secondary—)	1,750 × 50 yards

Very heavy bombers.

See Appendix XIII

2. **Number of runways or landing lanes.**—Although governed by local meteorological factors and facilities for construction, operational standards have been :—

Light aircraft—Two strips, divergently orientated to suit prevalent and heavy cross-winds.

Heavy aircraft—One. If two, either divergent or parallel.

For paved airfields in an active operational area, under semi-static conditions, the standard is two divergent strips best suiting the windrose, orientated without the assumption of a third strip being added subsequently.

The standard rule is that no urgent call for an additional runway exists, if cross-winds, of considerable frequency, have not a component, normal to any runway provided, in excess of 10 miles per hour.

For a diagrammatic layout of an airfield with one runway or landing lane, see Plate 2.

3. **Shoulders and graded areas.**—75 yards wide of each side of the runway or landing lane. Fit for crash or emergency landing, or run off. This makes a total width of 200 yards.

Shoulders and graded areas are reduced to 25 yards in certain circumstances, such as in operational emergency, or in difficult terrain or where open side drains are adopted.

4. **Overrun.**—200 yards long, at each end of strip or runway, fit for taxiing or premature touchdown.

5. **Flying approaches.**—Approach funnel or zone to be a trapezoidal area extending 2 miles from the 200-yard wide end of the strip, with a splay of 15 degrees laterally on each side. The width at 2 miles is thus approximately 2,000 yards.

Within this approach zone no obstacles are permitted which rise above a glide angle of 1 in 50, with a maximum of 1 in 30 in emergency. (Absolute maximum, U.S.A., 1 in 20.)

For night-fighter and night-bomber airfields, the range of clearance is extended to 3 miles minimum, with 5 miles as the most desirable standard.

6. **Turning circle.**—Standard diameter, 100 yards.

7. **Increased length for altitude or hot climates.**—Owing to variation in the performances of aircraft types, firm standards cannot be laid down.

A minimum increase of 7½ per cent. in length of run per thousand feet of altitude is commonly accepted for any change in atmospheric density, due to temperature or barometric pressure. Apart from altitude, increase of length is not demanded normally in the tropics as compared with standards elsewhere.

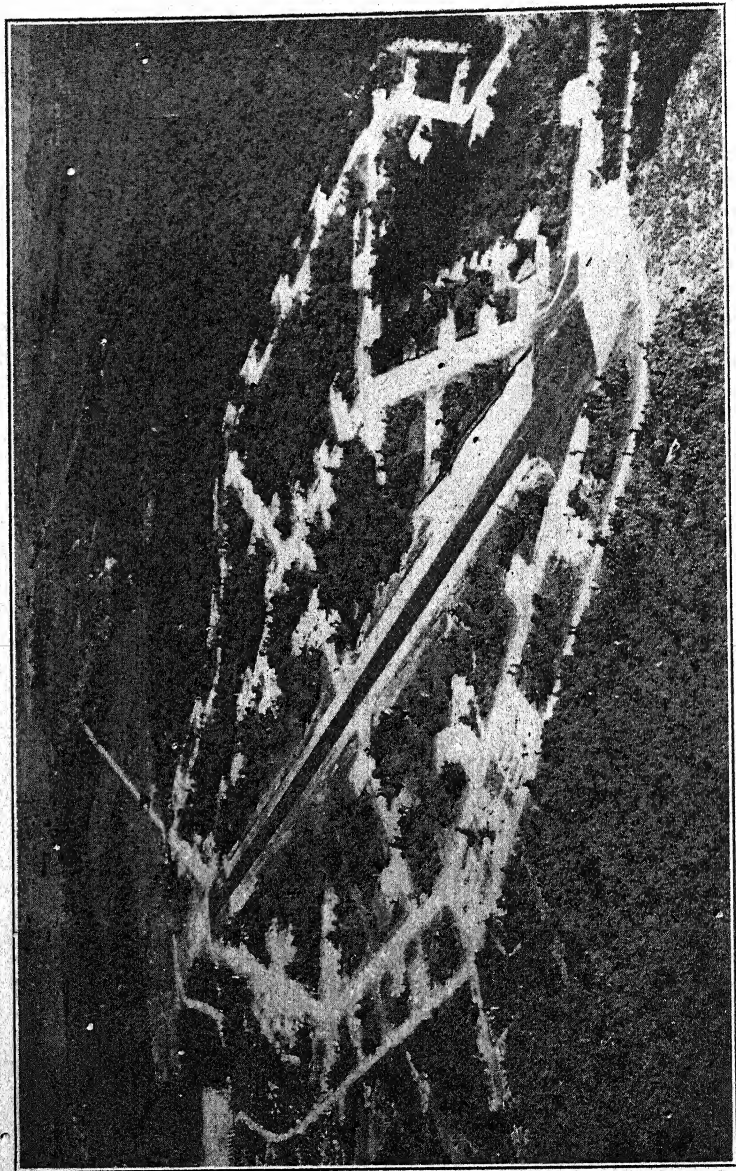


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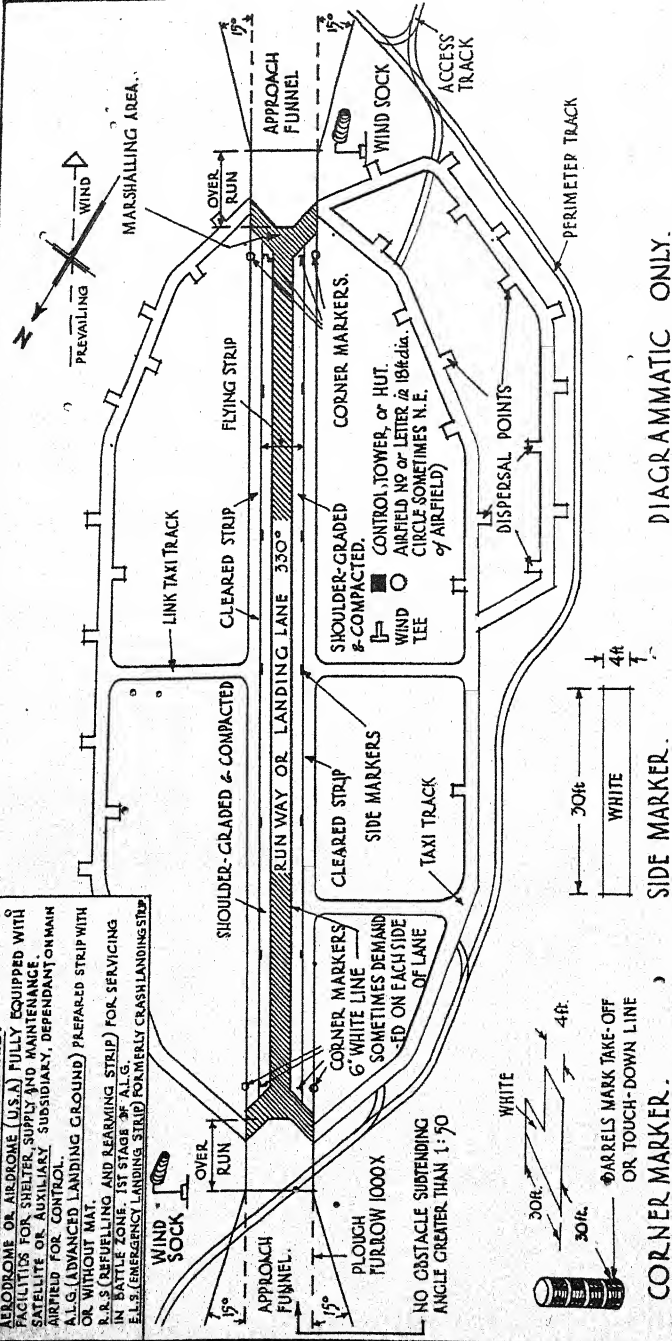
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6. **Turning circle.**—Standard diameter, 100 yards.

7. **Increased length for altitude or hot climates.**—Owing to variation in the performances of aircraft types, firm standards cannot be laid down.

A minimum increase of  $7\frac{1}{2}$  per cent. in length of run per thousand feet of altitude is commonly accepted for any change in atmospheric density, due to temperature or barometric pressure. Apart from altitude, increase of length is not demanded normally in the tropics as compared with standards elsewhere.

**TYPES OF AIRFIELD.**  
AERODROME OR AIRFIELD (USA) FULLY EQUIPPED WITH FACILITIES FOR WATER, SUPPLY AND MAINTENANCE. SATELLITE OR AUXILIARY, SUBSIDIARY, DEFENDANT OR MAIN AIRFIELD FOR CONTROL. A.G. (ADVANCED LANDING GROUND) PREPARED STRIP WITH OR WITHOUT MAT. P.R.S. (REFUELLING AND REARMING STRIP) FOR SERVICING IN BATTLE ZONE. 1ST STAGE "A" A.G. E.L.S. (EMERGENCY LANDING STRIP) FOR MERELY CRASH LANDING STOP.



## PLATE 2.—AIRFIELD STANDARDS

Maximum transverse grades	...	Normal 1:60	Acceptable 1:40
Maximum longitudinal grades	...	1:80	1:40

9. **Changes of grade** (Runway, landing lane or flight strip).—Rate of change of longitudinal gradient should not exceed 0.5 per cent. per 100 feet, which means that changes of grade should be made with vertical curves of 20,000 feet radius. No vertical curves should be less than 300 feet in length. It is desirable that there should be 300 yards of straight gradient between adjacent tangent points of succeeding curves, although in operational areas 300 feet of straight gradient has been accepted. The ideal is that from a height of 10 feet above the runway, at any point, the whole of the surface should be in sight.

U.S.A. standards are "Grade changes should not exceed  $\frac{1}{4}$  of 1 per cent., preferably  $\frac{1}{2}$  of 1 per cent., in any 100 feet. Longitudinal intersecting grades should be joined by a vertical curve at least 500 feet in length. Tangent interval between curves should not be less than 1,000 feet."

A rough empirical standard for minor surface undulations, commonly adopted for rapid determination, is that the surface should be taken by a car at 40 m.p.h. without discomfort to a passenger in the rear seat.

10. **Soft Ground.**—Standards are difficult to lay down. The softness and braking effect of soft ground can only be determined by use, or by pilots taxiing the aircraft concerned over the doubtful surfaces.

Good guidance can be obtained by declutching a loaded vehicle at 25 m.p.h. and measuring the free-run, against standards established elsewhere upon similar soils known to be barely firm enough for service. On sandy ground, for example, this run, with a desert-tired "Utility", should exceed 80 yards.

#### SECTION 5.—TAXI-TRACKS

1. Standard widths :—				* Surfaced Area	Verge or Shoulder	Total Clearance
Fighters	...	...	...	35 ft.	10 ft.	100 ft.
Bombers	...	...	...	50 ft.	10 ft.	180 ft.

For specific aircraft, track width should be twice wheel-span with a cleared area on each side, equal to half wing-span.

2. Taxi-tracks should be as straight as possible, or in short straight sections joined by curves. Connecting horizontal curves to be of a radius of 125 feet minimum. No reverse curves.

3. Longitudinal grade, maximum—1:33 normal, 1:25 accepted.

Transverse grade, maximum—1:40.

Changes of grade, minimum radius—2,000 feet.

4. Visibility should be such that from a height of 10 feet at any point on the taxi-track, the surface for at least 200 yards is in sight.

For layout of taxi-tracks and standings upon an airfield with dispersed runways, see Plates 3 and 4.

5. Upon transition of airfields from operational functions to base or staging service, modifications in taxi-track and hardstanding provision may have to be carried out to afford speedier access to and from runways. Additional run-off tracks are spaced along the runway at points where the aircraft served are most likely to end their run. These tracks are normally about 500 yards apart. See Plate 5.

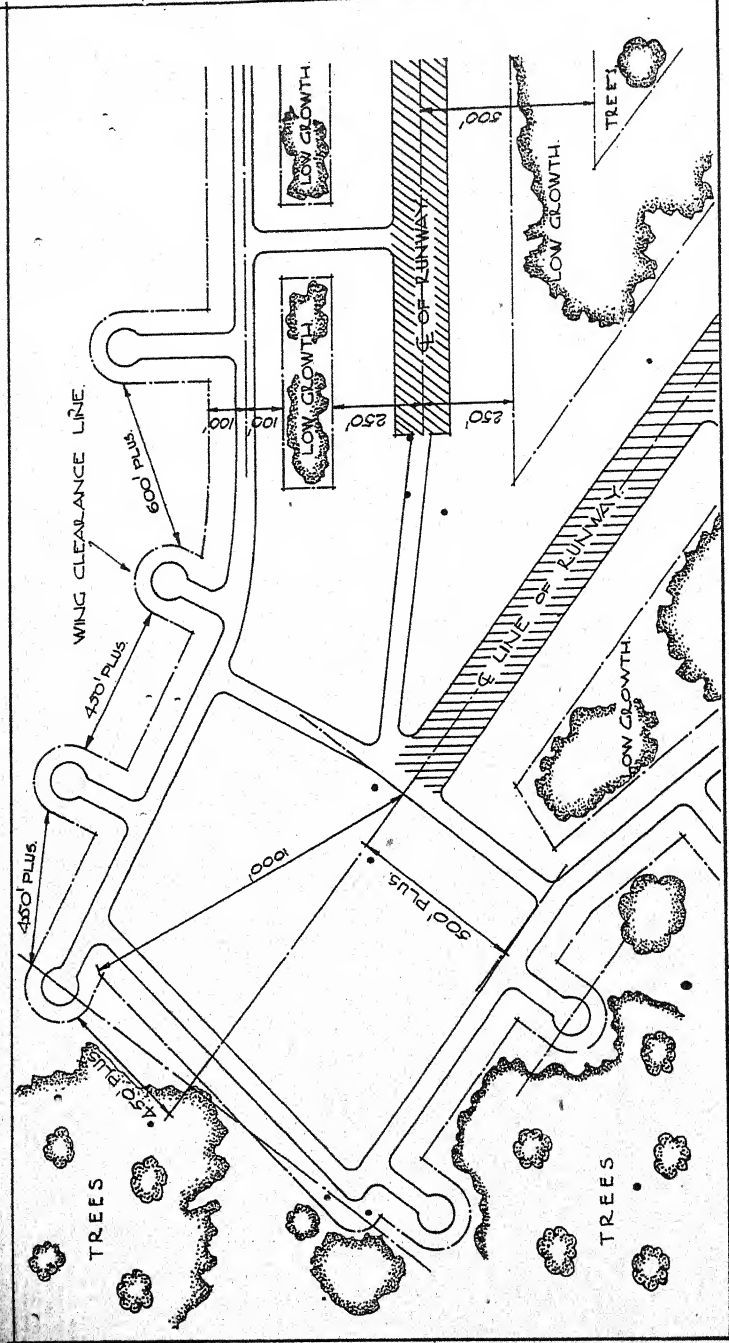
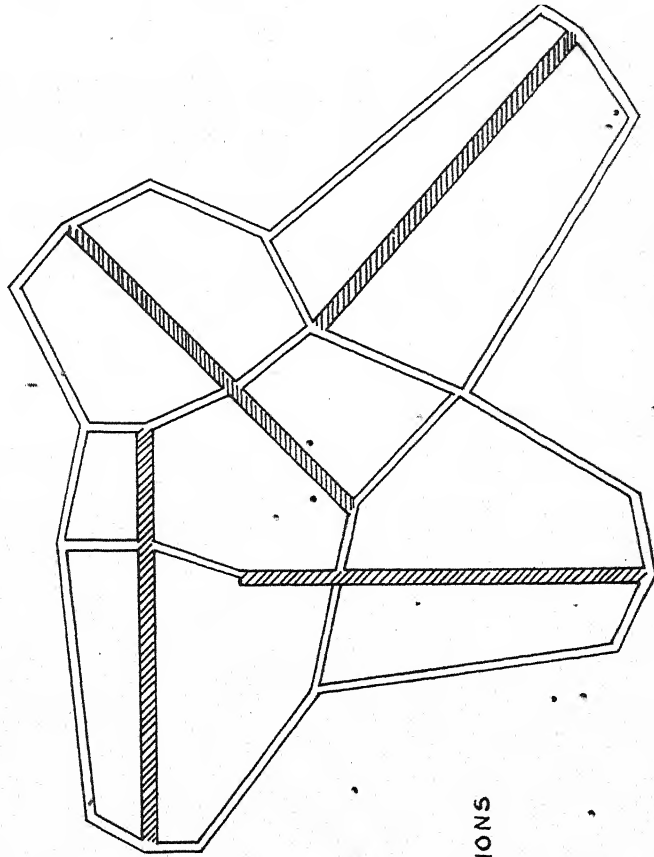


PLATE 3.—TYPICAL APPLICATION OF CLEARANCE RESTRICTIONS



• TAXI-TRACKS REQUIRED TO CONNECT HARD STANDING AREAS WITH BOTH ENDS OF EACH RUNWAY.

• TAXI-TRACKS SHOULD CONFORM WITH TERRAIN PATTERN TO FACILITATE CONCEALMENT.

• TAXI-TRACKS 50 FEET WIDE LAID OUT IN STRAIGHT SECTIONS WITH A MINIMUM OF TURNS SHARPER THAN 90°.

PLATE 4.—TYPICAL AIRFIELD LAYOUT WITH DISPERSED RUNWAYS

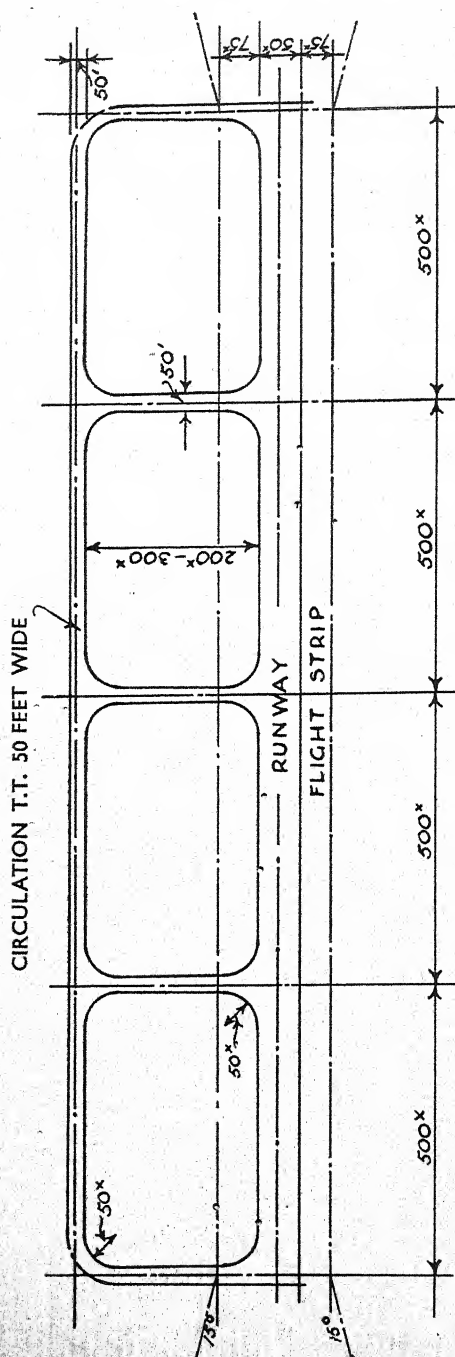


PLATE 5.—TYPICAL LAYOUT OF TAXI-TRACKS AND HARDSTANDINGS UPON AN AIRFIELD WITH  
DISPERSED RUNWAYS

## SECTION 6.—HARDSTANDINGS

1. Dispersal layout is particularly difficult to standardize and will inevitably be subject to firm local decisions.

2. In certain operational areas standards have been established as follows :—

Aircraft	Circle diameter or side of square	Distance apart of centres
Fighters and Light Bombers	40 ft.	Twin hardstanding—150 yds.
Medium Bombers	60 ft.	Twin hardstanding—150 yds.
Heavy Bombers	80 ft. (U.S.A. 100 ft. × 80 ft.)	Single—150 yds.

Methods of connecting these standings with taxi-tracks, where long dispersal lanes are unnecessary or impracticable, are shown in Plate 6.

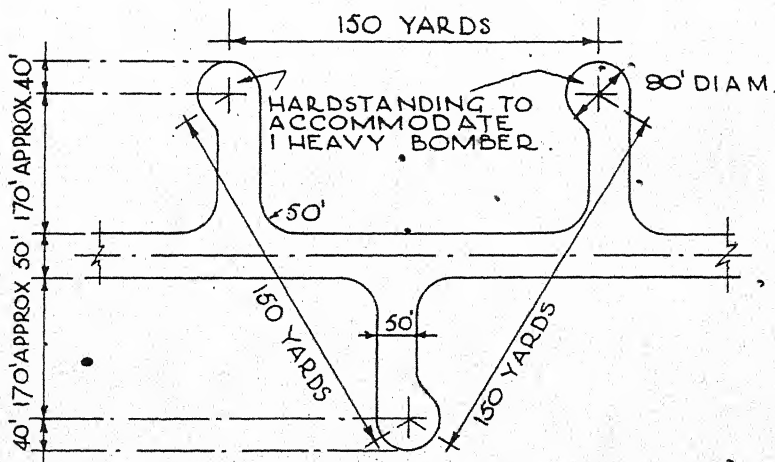


PLATE 6.—TYPICAL HARDSTANDING LAYOUT

Dispersal lanes should join hardstandings on right-hand side to allow aircraft to turn in left.

3. Surfacing of hardstandings should be to an oil and petrol resisting specification, but this demand need not apply to operational construction in the first instance. Where it has been necessary to construct hardstandings of sand asphalt or bitumen grouted-stone,



## SECTION 7.—AIRCRAFT PENS

1. Pens may be double or single. If double they should open in different directions. Distance apart, 150 yards.

Standard dimensions :—

Type of Aircraft	Width feet	Length feet	Height feet
Single-engine fighters (2), twin-engine fighters (1), or light bomber (1)	90	60	10—12
Medium bomber	104	85	12—14
Heavy bomber	130	85	14—16

Covered fighter pens 14 feet high.

No three pens (centres) to fall within a straight path, 40 yards wide, 500 yards long.

Underground fighter pens : ramp 1 in 15 ; semi-sunken bomber pens : 1 in 30.

2. Standard practice is to park aircraft in pens nose first, except fighters at readiness, or in safe areas, where pens are being used as maintenance shelters.

## SECTION 8.—AIRFIELD MARKINGS

1. Greater conspicuousness has been demanded in recent operations, by Air Formations, in the marking of runways and strips. Materials used depend on resources, but in all cases markings should be painted or selected to contrast with local ground colouring. The efficiency of markings is normally tested from a height of 3,000/4,000 feet.

2. Numbers or names of airfields should be placed at the N.E. corner of the surfaced area. Figures or letters should be 20 feet long.

End corner markings or beacons should be high enough to be conspicuous to the pilot during the run, upon landing or taking off. Arms of "L" corner markings should be 40 feet long by 4 feet wide.

Intermediate markings should be 30 feet by 3 feet, flush with the ground, 200 yards apart. Types used must not be or appear to be obstructions.

3. Markings for taxi-tracks and dispersal areas, though not commonly standardized, are important in many circumstances.

4. A cross with 20-foot arms, 3 feet wide, to be used for marking bad patches and dangerous ground. The perimeter to be marked with yellow flags in daytime and shielded red lights at night.

Where the run-over of a strip is particularly dangerous, it should be indicated by red and white markings, conspicuous from air and ground.

### SECTION 9.—BEARING STRENGTH OF SURFACES

Lacking specific instructions, the following standards may be taken for general guidance in considering the bearing capacity of natural soils and flexible pavements :—

Type of aircraft	Gross Weight lb.	Wheel Load lb.	Tyre Pressure lb.	Contact area per wheel sq. ins. (approx.)
Heavy bomber	60,000	37,500	75	500
Medium bomber	30,000	18,750	65	300
Fighter	14,000	8,750	55	150

Wheel load is taken at half gross weight, plus 25 per cent. (U.S.A.).

### SECTION 10.—PETROL STORAGE

In operational areas, before provision of tank storage, barrels or tins of petrol may be held in dispersed dumps on the following scales per squadron :—

	<i>Gals.</i>
Fighter squadron ... ..	10,000
Light bomber squadron ... ..	20,000
Medium bomber ... ..	25,000
Heavy bomber ... ..	45,000

### SECTION 11.—CAMP SITES

Minimum standards commonly accepted by a tactical air force are :—

Squadrons : 1 k.m. from landing strips or dispersal area.

Wings : 2 k.m. from landing strips or dispersal area.

Camps should not be sited up-wind or down-wind of the main (prevalent wind) landing strip.

### SECTION 12.—UNITS OF WORK

In all work and reports upon airfields, linear, square or cubic measurements will be given in Imperial units. Major dimensions are commonly expressed in yards by British units and in feet by American.

Metric system may be employed for geographical distances in view of the general use of kilo. road measurements abroad.

### SECTION 13.—SOUTH PACIFIC STANDARDS

1. The requirements specified below have interest in their special application to conditions in the Southern Pacific. Certain engineering details, not customarily included in airfields standards, are covered in these instructions.

#### 2. Runway dimensions

Aircraft	Length	Width	Shoulders
Fighter	4,000 ft.	150 ft.	50—75 ft.
Medium bomber	5,800 ft.	150 ft.	50—75 ft.
Heavy bomber	6,500 ft.	150 ft.	50—75 ft.

3. **Clearance.**—Minimum width for early operations, 300 feet, widened subsequently to 500 feet for all fields. No grading outside the shoulders is involved.

4. **Marshalling areas.**—Warm-up or marshalling areas, at each end, 500 feet by 200 feet.

5. **Gradients.**—Runway and shoulders at 1.5 per cent. both ways from centre line of runway, down to an open drain, 6 feet wide and 3 feet deep along each side. The apex or crown along the centre line should be rounded off to approximately 50 feet radius curve.

Maximum longitudinal gradient 1.5 per cent. with vertical curves at all changes of grade.

6. **Approaches.**—The approach zone to be a trapezoidal area stretching from the end of the full runway clearance for a distance of two miles on fighter airfields, and three miles for bomber airfields. Sides of zone spayed outwards at 10 degrees. All trees and obstructions to be removed within vertical angle of 1 in 40 for fighter, and 1 in 50 for bomber fields.

All tree stumps to be removed for a distance of 500 feet from the ends of the runway.

7. **Taxi-tracks.**—Taxi-tracks should be straight lengths connected by easy curves.

*Widths :—*

Aircraft	Surfaced	Graded only	Cleared
Fighters	40 ft.	50 ft.	90 ft.
Bombers	50 ft.	60 ft.	175 ft.

*Gradients and alignment :—*

Minimum 2 per cent. from centre line, both ways, to open ditches 6 feet wide by 2 feet deep. Crown of track graded to approximately 50 feet curve.

Maximum grade along taxi-track, 3 per cent.

#### 8. Hardstandings

Fighter ... .. 100 ft. wide (40 ft. surfaced)  
 Bomber ... .. 175 ft. wide (60 ft. surfaced)

*Distances apart of standings :* Fighter 300 feet or 125 feet if constructed as pens. Bomber 400 feet.

#### 9. Pens

Aircraft	Entrance width	Depth	Rear width	Height
Fighters	60 ft.	50 ft.	30 ft.	10 ft.
Bombers	120 ft.	70 ft.	50 ft.	15 ft.

10. **Perimeter tracks.**—Width 20 feet.

11. **Surfacing.**—Specifications are generally given in thickness of coral.

For runway surfacing and marshalling areas : Fighters 8-inch coral, medium bombers 12-ins. and heavy bombers 18-ins. minimum thickness. For base course, under pierced steel planking, 8 to 12 inches of coral or gravel.

Taxi-tracks : 8-ins. minimum thickness, coral surface.

Hardstandings : Fighters, 8-ins. thickness ; bombers, 10-ins. thickness.

Perimeter tracks : 8-ins. thickness.

#### SECTION 14.—TROOP-CARRIER LANDING GROUNDS (SOUTHERN PACIFIC)

1. Standards for initial troop-carrier landings :—

(Transport planes)

				<i>Minimum</i>	<i>Desirable</i>
Runway lengths	...	...	...	2,700 ft.	4,000 ft.
Strip (width)	...	*	...	90 ft.	200 ft.
Clearance (width)	...	...	...	150 ft.	350 ft.

In the cleared area, beyond the sides of the strip, all trees, stumps, logs and rocks should be removed, but the grass need not be cut below a height of  $3\frac{1}{2}$  inches.

Approach zone, glide angle assumed, maximum 1 : 30, normal 1 in 40.

2. **Gradients.**—Strip cross-fall 3 per cent. The former standard of 2 per cent. is considered inadequate in tropical areas of high rainfall, unless ground very absorbent.

Longitudinal grading—normal maximum 3 per cent.

Rolling grades permitted provided :—

- (a) Lengths of tangents not less than 1,000 feet.
- (b) Slopes not greater than 3 per cent.
- (c) Vertical curves between tangents not less than 200 feet. Change of grade not more than 1 per cent. per 100 feet of curve.
- (d) Visibility is unobstructed from any point 10 feet above surface to any other point 10 feet above surface.

3. **Layout.**—Two or more strips to provide for necessary landings and one spare for maintenance. Whether three are required depends on density of landings, durability of strips and time available for their maintenance.

Drainage channels at edges of cleared area with side slopes of 1 : 15.

OFFICERS' QUARTERS. USUALLY A LITTLE FURTHER AWAY FROM L. G. THAN MEN'S BARRACKS, AND THE LAYOUT IS LIKELY TO BE MORE ELABORATE.

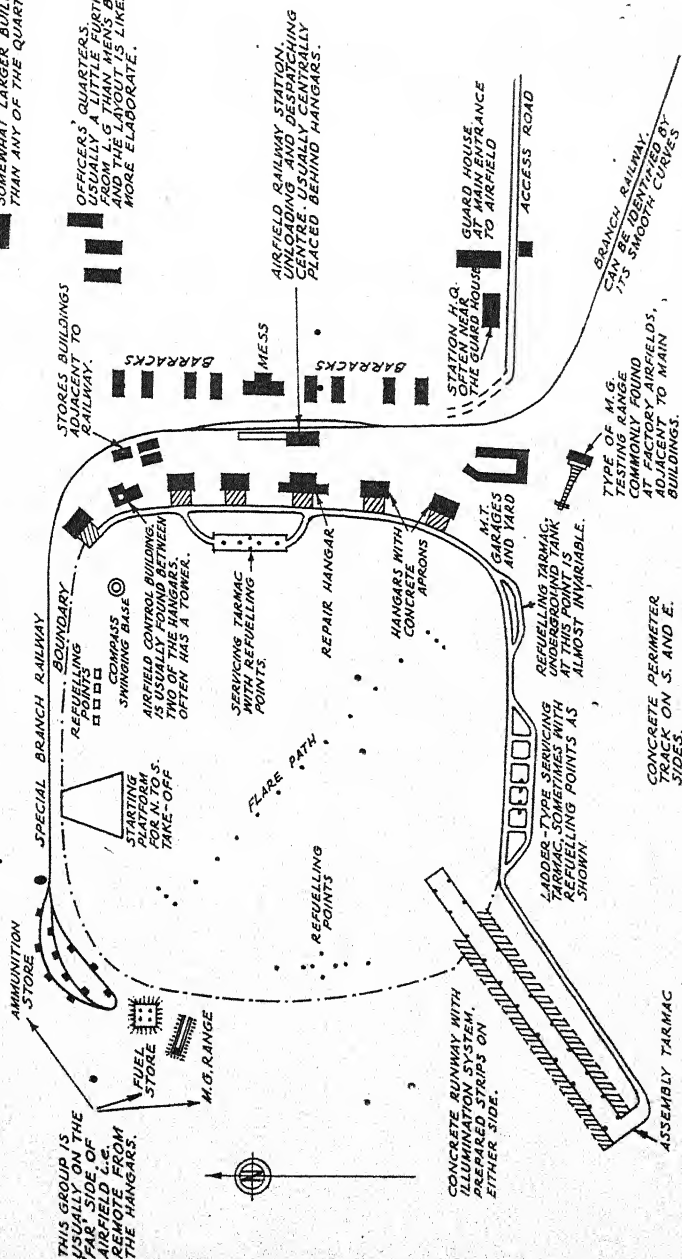


PLATE 9.—TYPICAL LAYOUT OF STATIC GERMAN AIRFIELD

## CHAPTER 2

## SOIL TYPES AND PROPERTIES

## SECTION 15.—GENERAL

1. Experience in judging the behaviour of common types of soil, under varying climatic conditions, is required by engineer officers on reconnaissance and construction. It enables them to decide quickly upon the suitability of a site and upon the most effective measures to be taken, for alleviation of dust, for paving and drainage. Close visual examination of an area, backed by a few field tests, will be commonly sufficient for the initial task.

2. In the subsequent laying out of permanent work, the engineer should possess a knowledge of :—

- (a) Classification of soil types so that accumulated and recorded experience from other sources can be readily applied ;
- (b) the principles governing the effects of soil type on engineering methods and behaviour in airfield service.

3. An airfield for heavy duty is a concentrated task of such great magnitude that minor modifications of design may result in big economies in time and materials. Soil and climate are the primary factors upon which designs are based.

4. Soil types and properties are dealt with under the following heads :—

- (a) Factors governing the engineering properties of soils.
- (b) How soil types affect surfacing requirements.
- (c) Classification of soils.
- (d) Soil types and their identification in the field.
- (e) Laboratory tests on soils.
- (f) Practical interpretation of data.

Soil surveys are dealt with in Chapter 5, covering airfield surveys in general.

## SECTION 16.—FACTORS GOVERNING THE ENGINEERING PROPERTIES OF SOILS

1. The main factors are :—

- (a) Soil type.
- (b) Moisture content.
- (c) State of compaction.

In addition, there are important subsidiary factors, as a rule closely associated with the above, *e.g.*, the drainage characteristics of the soil. All these factors can vary independently of each other. A wide range of soil conditions is thus possible. Diversity of climate and rainfall imposes additional complexity.

2. Soil is composed of mineral particles of varying size from gravel or shingle on the one hand to plastic clay on the other. The classification of soil type is based mainly on grain-size. Mineral composition of a clay may also be important.

Coarse-grained soils are non-cohesive in the dry state, whilst the finer grained soils are cohesive. This constitutes a major division.

Fibrous organic soils, such as peat, form a special group.

3. The moisture content of the soil is chiefly important in cohesive soils, since the strength of a given soil varies more or less inversely as its moisture content. On the other hand the stability of non-cohesive soils is much less affected by the moisture content.

4. The state of compaction of the soil is important from several points of view. Loosely compacted soil settles easily when a load is imposed—it possesses less inherent stability. Further, the higher percentage of voids enables the soil to absorb more water than one more densely compacted, and hence to soften more readily.

## SECTION 17.—HOW SOIL TYPES AFFECT SURFACING REQUIREMENTS

1. If a cohesive soil can be kept air-dry and not allowed to absorb water, its stability is maintained indefinitely. The use of bitumenized hessian or a thin layer of sand-bitumen mix is an application of this principle.

Failure will be experienced, if a cohesive soil is damp and soft at the time of construction; or if it is found impossible over a long period of time to prevent entry of moisture through damaged surfacing, or through cracks in paved areas. Water then accumulates and softens the soil.

To provide against the weakening of sub-grade with paving specifications, it is necessary to adopt heavy construction to distribute the loads sufficiently to prevent deformation under traffic.

2. Since non-cohesive soils do not soften in the same way, and also drain freely, they require considerably less thickness of base than runways on cohesive soils, which may be expected to soften with time, even though initially hard. Design charts used in permanent runway design thus call for much more substantial construction for flexible pavements on cohesive soils than on non-cohesive soils. For concrete pavements, greater thickness is demanded on heavy clay sub-grades.

3. The type of soil is thus an essential element in design. Whether a given site, in its observed state, will carry traffic is a question that, as a rule, can be determined easily. It is also possible to deduce the type of construction that will carry traffic indefinitely for conditions of unlimited use. But the important problem of cutting down standards for short service, commonly essential under war conditions, is one of greater complexity.

## SECTION 18.—CLASSIFICATION OF SOILS

The primary classification of soils, now generally adopted by airfield engineers, is tabulated below :—

Table I.—Classification of soils

Soils	Type	Nature	Symbol
Coarse grained	Gravel and gravelly	Well graded, fairly clean Well graded, clay binder Poorly graded, fairly clean Excess of fines	GW GC GP GF
	Sands and sandy	Well graded, fairly clean Well graded, clay binder Poorly graded, fairly clean Excess of fines	SW SC SP SF
Fine grained	Silts, very fine sands, rock flour	Low compressibility. Silts, rock flour, clayey fine sands. High compressibility. Micaceous or diatomaceous fine sand and silty soils.	ML MH
	Clays (inorganic)	Low compressibility. Medium plasticity. Sandy and silty clays. High compressibility. High plasticity. Fat and heavy clays.	CL CH
	Clays (organic)	Low compressibility. Organic silts. High compressibility. Organic clays. Medium high plasticity.	OL
	Fibrous (organic)	Very high compressibility.	OH Pt

This primary scheme will be amplified in subsequent sections.  
Symbols will not be used in engineer messages or reports except by pre-arrangement.

## SECTION 19.—SOIL TYPES AND THEIR IDENTIFICATION IN THE FIELD

1. The primary soil constituents or types, which the engineer officer should be able to identify readily in the field, are : gravel, sand, silt, clay, and peat. These form the basis for the classification of the many transitional types and mixtures found in the field, which are named after the predominant constituent, with a qualification denoting either the less important constituent or some simple physical characteristic (*e.g.*, silty sand, sandy clay and medium gravel).

In addition, there are certain combinations of these constituents which call for special names because of their wide occurrence (*e.g.*, loam, marl), or of their importance in certain regions (gumbo, hoggins, and cotton soil).

"Caliche" is also a useful term, often appearing in reports from U.S.A. and Mediterranean regions, meaning decomposed limestone containing silt and clay. "Hardpan" is a common name for a solid layer which has become compacted and hardened by pressure or some other natural process of cementation.

2. Features of the above primary constituents are as follows:—

- (a) *Gravel*.—Diameter of particles, 20-mm. to 2-mm. Classified according to size and uniformity as coarse, medium, or fine; well or evenly graded, angular, flat or rounded.

Deposits of gravel commonly contain a considerable percentage of sand and even silt or clay.

- (b) *Sand*.—Particle sizes are classified as coarse, 2.0-mm. to 0.2-mm. and fine, 0.2-mm. to 0.02-mm. Coarse sand may be compared in sizing with sugar, from granulated to castor varieties. Fine sand is about the size of table salt down to a very fine grain still perceptibly gritty, before passing into "silt".

- (c) *Silt* ("Rock Flour") 0.02-mm. to 0.002-mm. This inorganic type of silt, sometimes mistaken for clay, is rarely found alone, but is a common constituent of mixed classifications, such as sandy silt or silt clay. Silt lacks plasticity and possesses little or no cohesion when dry.

For identification in the field, three tests can be employed.

- (i) "Shaking test." Prepare a pat of wet soil, adding water if necessary. Shake horizontally in the palm of the hand. With typical silt, water will come to the surface of the sample, which then appears glossy and soft. By squeezing, water disappears from the surface as though dried up, and the sample stiffens and finally cracks or crumbles.
- (ii) "Breaking test." Allow sample to dry and test its cohesion and "feel" by breaking up with the fingers. Little or no cohesion is shown and the lack of any perceptible grittiness distinguishes the soil from a fine sand.
- (iii) "Powder test." If, on rubbing the dry soil between the finger and thumb, a fine powder is left on the "finger prints" of the hand, there is a considerable quantity of silt in the soil.

- (d) *Clay*.—Particles less than 0.002-mm. Clay consists of the range from silt down to a colloidal particle, so fine as to remain suspended in water indefinitely.

All clays display, between certain moisture contents, the physical property known as plasticity. Depending on the degree of plasticity and contents of coarser grain sizes, one can distinguish between sandy clays, silt clays, clays with low plasticity or "lean" clays, highly plastic clays or "fat" clays. Many clays, brittle in an undisturbed state, become very soft and plastic upon being worked.

Clays are classified by tests for plasticity, water content, compaction, shrinkage and expansion.

By remoulding a piece of clay and adding water as required, it will be transformed into a plastic mass which can be kneaded like dough. Hardness of a dried sample can be measured by intensity of finger pressure required to break up the sample. It may be easy to determine clay positively by this means, but experience is needed to ascertain the degree of plasticity.

The consistence of a clay *in situ* is independent of the above characteristics. Its hardness, *i.e.*, the ease with which it

can be excavated, ranges from hard to very soft. Dry clays are always hard and require the use of a pick for excavating. Some wet clays are soft and can be excavated with a shovel, but some are so compact that they still need spades or picks.

(e) *Peat and other organic soils*

- (i) Peat composed largely of partly decomposed vegetation can generally be identified with ease. The organic matter is relatively coarse and fibrous.
- (ii) Other organic soils, which may be classified under the silts and clays, comprise fine-grained plastic and non-plastic mineral sediments, with varying proportions of finely divided vegetable matter. In organic silts and clays, organic matter is usually so finely divided that it cannot be detected by visual means. Sometimes there is a characteristic odour which can be intensified by drying a small sample until the surface appears dry.
- (iii) Organic soils almost invariably make unsatisfactory sub-grades, owing to high compressibility and low shear strength.

## SECTION 20.—COMBINED SOIL TYPES

1. The various soil constituents are found in the field in a great variety of combinations, presenting an intricate range of form and engineering properties.

2. An important group is covered by the general term "loam" which refers to soils consisting of a mixture of the sand, silt and clay grades in varying but approximately equal amounts. The term is valuable for use during reconnaissance to designate a soil found to contain all three constituents, in proportions indeterminable with the means available.

- (a) *Sandy loam*.—Contains much sand, with sufficient silt and clay to make it fairly coherent. The individual sand grains can be readily seen and felt. Squeezed when dry, the soil forms a cast which breaks readily; when moist, the cast formed by squeezing can be handled, carefully, without breaking.
- (b) *Silt loam*.—Over half silt, contains a moderate amount of fine sand and a small amount of clay. When dry, the soil may appear quite "cloddy", but lumps can be easily broken. When pulverized, the soil feels soft and floury. Either dry or moist, the soil will form casts which can be handled freely without breaking. If squeezed between thumb and finger, it will show a broken texture without forming ribbons.
- (c) *Clay loam*.—A fine-textured soil which breaks into clods and lumps, which are hard when dry. When a moist sample is pinched between thumb and finger, it forms a thin ribbon, which breaks readily, barely sustaining its own weight. The soil is plastic and readily forms a cast, which bears much handling. When kneaded in the hand, it does not crumble, but tends to work into a heavy compact mass.
- (d) In addition, mixtures of two constituents will be commonly found, such as sand-gravel, silty clay or silty sand, which would call for specific reference in reconnaissance reports.

**3. Field tests.**—With experience, the main characteristics of many soils in a wet state can be distinguished by their "feel".

Identification of small quantities of silty or clayey material can be made by rubbing moist soil against the palm of the hand and then wiping off all grains of visible size. Examination of any material adhering to the hand permits, with a little experience, classification of the finest fraction.

A mixed soil can also be roughly classified in the field as follows :—

Reduce a dry sample to its finest state. Take a piece of rough paper, such as blotting paper, about the size of two foolscap sheets, and lay it on a slightly inclined board (about  $\frac{1}{4}$  inch in 1 foot). Leave  $\frac{1}{4}$  inch of the paper above the top edge of board. Pour a teaspoonful of the sample evenly across the paper. Grip the top of the paper between finger and thumb, and gently jerk the sand, by tapping the top of the board, gradually down the slope. The sand will grade itself out and a rough estimate of particle sizes and percentages can be obtained.

It is essential to gain experience of all field methods by practising upon various soils of known characteristics.

## SECTION 21.—LABORATORY TESTS ON SOILS

1. Laboratory work on soils of most practical importance comprises :

(a) *Identification tests*

- (i) Mechanical analysis.
- (ii) Liquid and plastic limit tests (with moisture content determination).

(b) *Tests of specific properties*

- (i) Compaction properties.
- (ii) Moisture content.
- (iii) Bearing capacity.

2. The following notes are based largely on the reports of the Road Research Laboratory, England, and the Manuals of the U.S. Aviation Engineers.

- (a) *Mechanical analysis.*—The mechanical analysis of a soil gives its grain-size distribution. The size distribution of the coarse particles is determined by sieve analysis, but the size distribution of the finer particles has to be based on their rate of settlement in water. This requires laboratory equipment, although with sandy soil rough indications can be obtained by sedimentation in a jar.

The mechanical analysis of the coarse material may be of considerable importance, notably in stabilized gravels.

- (b) *Index tests.*—The index tests (liquid and plastic limit tests) provide a means of identifying cohesive soils and are based on the fact that the finer grained soils require considerably higher moisture content to produce equal softening. (See Appendix IV.)

- (i) *The liquid limit* is defined as that moisture content at which the soil will just begin to flow when jarred a specified number of times on standard apparatus. At the liquid limit, the bearing capacity of the soil is practically zero. Liquid limit in conjunction with plastic limit, is of value in the identification and classification of fine grained soils.

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- (ii) *The plastic limit* is defined as the lowest moisture content, expressed as a percentage of the dry weight, at which a soil can be rolled into threads of  $\frac{1}{8}$ -inch diameter without crumbling. It is the moisture content at which cohesive soils pass from a semi-solid to the plastic state. If the natural moisture content of a soil is less than the plastic limit, the soil possesses relatively high stability.
- (iii) *Plasticity index* is defined as the numerical difference between liquid and plastic limit. A cohesive soil with a low plasticity index has better stability than one with a high value.
- (c) *Compaction* is the process by which soil grains are constrained to pack more closely together, thereby decreasing the void space, and increasing density and resistance to deformation of the soil mass. In the laboratory compaction test, a definite amount of ramming is applied to simulate field practice.  
 The density to which a soil can be compacted, with a given compaction effort, depends upon the moisture content. For all soils, a moisture content exists at which a given amount of compaction will produce the highest density. The moisture content at which this density is obtained is termed "optimum moisture", which decreases with an increase of compaction effort.  
 The practical interpretation of results is a question for an experienced staff. This is of special importance on permanent runway construction.
- (d) *Moisture content* is expressed in percentage of dry weight of soil. In general, determinations are made by placing a sample in a metal container and thoroughly drying out in an oven or over a fire. (See Appendix V.)
- (e) *Bearing capacity*.—Methods have been developed in U.S.A. for measuring in the laboratory the bearing or load capacity of a sub-grade or base material. Results are expressed in terms of a percentage, based on a standard sample of crushed stone. These methods allow miscellaneous materials and mixtures to be tested. Normally, the bearing capacity of natural surfaces is tested *in situ*, manually or with simple equipment. (See Appendix VI.)

## SECTION 22.—PRACTICAL INTERPRETATION OF DATA

1. The complexity of soil types and physical characteristics is less apparent when the problems of a particular region call for study. The range of types may be reduced to very few, owing to uniform climate and closely related geological origin. Upon first reconnaissance, the soils on an airfield site may require less consideration than water-level, surface contours, and other topographical features.

In operations, the tactical demands will be so urgent, the choice of site so restricted, and engineering risks so fully justified, that details of soil analysis may appear almost academic. But it will be impossible for engineer officers to look ahead and foretell the results of drought or rains without fairly detailed knowledge of conditions.

2. Sooner or later, any of the following practical questions are likely to call for detailed report.

- (a) Behaviour of natural surface under the measure and incidence of rainfall known to be typical for the district and season. (Time of drying out after different spells of rain.)
- (b) Effect of such rainfall upon bearing capacity of soil for specified aircraft, or upon its strength as a foundation for various methods of pavement.
- (c) Effect of rainfall in delaying the work of grading, rolling, transport, track-laying, etc.
- (d) Suitability of soil for different types of available metal track or other portable surfacing.
- (e) Drainage characteristics of soil and site.
- (f) Durability of dry natural surface after heavy use, with special regard to incidence of dust and soft patches.
- (g) Effects on surface conditions of high water table.
- (h) Sometimes, effects of frost and thaw.

3. Direct evidence will be obtained from intelligence reports and from work in the field, by study of vehicle-tracks and vegetation, by visual soil tests, and by correlation or "matching" of observed conditions with those known or recorded elsewhere.

The results of laboratory tests will provide important supplementary data, allowing soils to be classified in accordance with the Casagrande scheme, which displays the practical behaviour of standard soil types.

4. The following analysis is condensed from the table given in the U.S. "Aviation Engineers' Manual TM5-255," and covers physical characteristics affecting work both on advanced landing grounds and upon more static tasks:—

(Types are grouped in sequence, from the coarsest to the finest grades.)

(GW) *Well-graded gravel and gravel-sand mixtures: little or no fines*

Cohesion—Nil  
Wearing surface—Poor  
Foundation—Excellent  
Shrinkage and expansion—Insignificant  
Drainage—Excellent  
Compaction—Excellent

(GC) *Well-graded gravel-sand-clay mixtures*

Cohesion—Medium to high  
Wearing surface—Excellent  
Foundation—Excellent  
Shrinkage and expansion—Very slight  
Drainage—Practically impervious  
Compaction—Excellent

(GF) *Gravel with excess of fines, very silty gravel, clayey gravel, poorly graded gravel-sand-clay mixtures*

Cohesion—Slight to high  
Wearing surface—Fair to good  
Foundation—Good to excellent  
Shrinkage and expansion—Very slight  
Drainage—Fair to impervious  
Compaction—Good. Close control essential

(SW) *Well-graded sands : little or no fines*

Cohesion—Nil  
 Wearing surface—Poor  
 Foundation—Excellent  
 Shrinkage and expansion—Practically nil  
 Drainage—Excellent  
 Compaction—Excellent

(SC) *Well-graded sand-clay mixtures*

Cohesion—Medium to high  
 Wearing surface—Excellent  
 Foundation—Excellent to good  
 Shrinkage and expansion—Very slight  
 Drainage—Practically impervious  
 Compaction—Excellent

(SP) *Poorly graded sands : little or no fines*

Cohesion—None  
 Wearing surface—Poor  
 Foundation—Good to fair  
 Shrinkage and expansion—Practically nil  
 Drainage—Excellent  
 Compaction—Good

(SF) *Sand with excess of fines, very silty sands, clayey sands, poorly graded sand-clay mixtures*

Cohesion—Slight to high  
 Wearing surface—Fair to good  
 Foundation—Fair  
 Shrinkage and expansion—Practically none to slight  
 Drainage—Fair to practically impervious  
 Compaction—Good—Close control essential

(ML) *Silts and very fine sands, rock flour, silty or clayey fine sands*

Cohesion—Very slight to medium  
 Wearing surface—Poor  
 Foundation—Fair to poor  
 Shrinkage and expansion—Slight to medium  
 Drainage—Medium to poor  
 Compaction—Good to poor. Close control essential

(CL) *Clays, inorganic, of low to medium plasticity, sandy clays, silty clays, lean clays*

Cohesion—Medium to high  
 Wearing surface—Poor  
 Foundation—Fair to poor  
 Shrinkage and expansion—Medium  
 Drainage—Practically impervious  
 Compaction—Fair to good

(OL) *Organic silts and organic silt-clays of low plasticity*

Cohesion—Slight to medium  
 Wearing surface—Poor  
 Foundation—Fair to poor  
 Shrinkage and expansion—Medium  
 Drainage—Practically impervious  
 Compaction—Fair to good

(CH) *Clays, inorganic, of high plasticity; fat clays*

Cohesion—High

Wearing surface—Very poor

Foundation—Poor to very poor

Shrinkage and expansion—High

Drainage—Practically impervious

Compaction—Fair to poor

(Pt.) *Fibrous organic soil of very high compressibility. Peat and other organic swamp soils*

Wearing surface—Useless

Foundation and wearing surface—Useless

Shrinkage and expansion—Very high

Drainage—Fair to poor

Compaction—Impracticable

*Potential frost action is recorded as follows:—*

ML, CL, OL	...	...	...	...	Medium to high
GC, SC, CH	...	...	...	...	Medium
GF, GW, GP, SW, Pt.	...	...	...	...	Slight to Nil
SF	...	...	...	...	Variable

*Compaction.*—Sheepsfoot rollers can be best used with GC, SC, CL, OL, and CH, and rubber-tyred rollers with GF, SF, and ML.

5. **Contraction.**—A soil characteristic of special importance in climates of marked seasonal contrast is the degree of contraction displayed upon drying out. Silty clays of "cotton soil" type commonly show linear contraction of over 15 per cent. and constitute a troublesome foundation, especially in fills, if allowed to regain high moisture content.

## SECTION 23.—SOIL CONSISTENCE DEFINITIONS

Soil consistence, readily determined upon airfield reconnaissance, is a factor of importance in identification of soils and also in the assessment of engineering properties. The following list of terms is given for the benefit of reconnaissance officers who may be able, in many cases, to use such definitions in the speedy reporting of soil conditions.

<i>Term</i>	<i>Interpretation</i>
Brittle	... Dry soil breaks with clean sharp fracture.
Cellular	... Pore spaces of regular size throughout soil mass.
Cemented	... Soil aggregates bound together by a cementing agent.
Cheesy	... Characteristic of a wet soil. Elastic, bends without fracture.
Coherent	... Very compacted.
Compact	... Dense and firm without cementation.
Firm	... Moderately hard. Fragments can be broken between fingers.
Friable	... Easily broken and reduced to crumb structure.
Hard	... Very difficult to crush between fingers only.
Impervious	... Very resistant to water or root penetration.
Loose	... Soil of small aggregates and maximum pore space.
Mellow	... Porous mass, softer than friable; no tendency to pack.
Porous	... A visible condition of permeability, dependent on the size, shape and quantity of air spaces within the mass.

<i>Term</i>	<i>Interpretation</i>
Plastic ...	Readily moulded.
Soft ...	Readily crushed between fingers.
Sticky ...	Adhesive when wet, cohesive when dry.
Tenacious ...	Very like sticky, but applies more to a cohesive character when wet.
Tight ...	Compact, impervious and tenacious, usually plastic.
Tough ...	Bores easily, but very difficult to break.

## CHAPTER 3

### METEOROLOGICAL DATA

#### SECTION 24.—GENERAL

1. Abundant information is provided by units of the Meteorological Office, whether attached to the Army or Air Force, when required for planning. Figures may be issued with the warning that they originated from stations far from the sites under consideration, and that local modifications may be necessary because of varying topographical features.

2. The engineer officer must try to check the bearings given for prevalent wind by study of vegetable life, sand-dune patterns, orientation of wind-scoops on houses, etc., and by enquiry. The existence of any ridges or depressions, liable to cause local wind turbulence in the line of air approaches, must be recorded and reported. Rainfall records will be scanty in poorly developed regions and must be amplified from all possible direct and indirect sources of information. Fog and mist are important. Information may be gathered from local sources, but whenever possible such data should be supplemented by the advice of a meteorological officer who, even when he has no relevant records, can give an opinion as to whether the information is likely to be correct. Assessment of dust storm expectations is an engineer responsibility of great practical importance in certain countries. The meteorological officer can assist in this by giving information on the direction from which dust-raising winds are most common.

#### SECTION 25.—RAINFALL

1. Rainfall records will be required for all areas of proposed activity, in order to plan suitable methods of runway surfacing and drainage construction. Data should cover :—

- (a) Rainfall and evaporation : annual and monthly averages.
- (b) Disposition of wet and dry periods.
- (c) Maximum intensity.

Figures of monthly precipitation are of particular importance in regions of seasonal extremes.

2. In some parts of the world monthly and even annual records show baffling irregularity. On one island in the Pacific rainfall returns gave, for a particular month, a minimum of 0.3 inch, an average of 3.3 inches, and a maximum of 11.3 inches. A calendar month is too short a measure in countries of extreme conditions. The seasonal picture is more instructive.

3. For purposes of illustration, the rainfall distribution throughout the year for a variety of regions selected for their importance or distinctive characteristics, is shown in Table II below. Comparable figures should be obtained for any other district under consideration for airfield construction.

Table II.—Rainfall distribution

Month	Equable distribution			Seasonal extremes			
	S.E. England.	France. Arras.	Germany. Berlin.	Sicily. Syracuse.	North Africa. Algiers.	Palestine. Ramleh.	Assam. Srimangal.
	ins.	ins.	ins.	ins.	ins.	ins.	ins.
Jan. ...	1.9	2.1	1.5	3.8	4.6	5.4	0.5
Feb. ...	1.7	1.6	1.5	2.4	3.6	3.4	1.5
Mar. ...	1.8	2.0	1.7	1.6	2.9	1.9	4.3
Apr. ...	1.5	1.6	1.5	1.4	1.6	0.7	10.7
May ...	1.8	2.2	1.9	0.8	1.6	0.1	15.0
June ...	2.0	2.5	2.5	0.2	0.6	0.0	17.1
July ...	2.4	2.5	3.0	0.2	0.1	0.0	16.5
Aug. ...	2.2	2.4	2.2	0.3	0.2	0.0	13.2
Sept. ...	1.8	2.4	1.7	2.0	1.7	0.0	11.8
Oct. ...	2.6	2.6	1.9	3.3	2.8	0.8	6.8
Nov. ...	2.4	2.4	1.7	5.1	5.0	2.2	0.9
Dec. ...	2.4	2.4	1.8	3.9	5.1	3.7	0.2
	24.5	26.7	22.9	25.0	29.8	18.2	98.5

At Cherrapunji, Assam, average rainfall is 424 inches, with 274 inches during June, July, and August, and  $6\frac{1}{2}$  inches during the four months, November to February.

#### SECTION 26.—EVAPORATION

1. Evaporation can only take place from a surface which contains water. Most evaporation records give the evaporation from an artificially moistened surface or from a water surface, and so give values of moisture removal which have no relation to the moisture removal from the natural surface of the ground.

2. The rate of total evaporation from soil, including transpiration by plants, varies according to the season, the weather conditions and the amount of moisture available for evaporation in the upper few feet of the soil. Formulae, taking these factors into account, are being developed for giving the rate of evaporation for bare and turfed soil.

3. The following table gives the approximate total evaporation for turfed grassland on chalk in Hampshire :—

Table III.—Total evaporation

<i>ins.</i>				<i>ins.</i>			
January ...	...	...	0.4	July ...	...	...	2.7
February ...	...	...	0.5	August ...	...	...	2.6
March ...	...	...	1.1	September ...	...	...	2.4
April ...	...	...	1.9	October ...	...	...	1.7
May ...	...	...	2.5	November ...	...	...	1.0
June ...	...	...	2.6	December ...	...	...	0.5
Total per year ...				19.9 ins.			

4. On heavy grassland which has dried out to the normal mid-summer state, 1 inch of rain will bring the top 4 inches to field capacity, 2 inches will extend to a depth of 9-10 inches, and 3 inches to about 18 inches. Soil is at field capacity when all the major pore spaces are saturated with water. The above figures are approximate only, and it is assumed that the rainfall was almost continuous, so that loss by evaporation can be ignored.

5. Approximate figures for evaporation after heavy rain in the summer in England are that 0.18 inch will evaporate in the first three days, 0.20 inch in the next three days, and 0.12 inch in the following three days. In winter the rate of evaporation will be very much less.

#### SECTION 27.—EFFECTS OF RAINFALL AND EVAPORATION

1. The interaction of these two factors is significant. As is seen from the preceding sections, in England and much of Europe where there are no marked wet and dry seasons, evaporation is most important in summer, and in winter is quite unable to remove the water which normally falls in rain.

2. In a Mediterranean climate, such as Syracuse, Algiers, or Ramleh, there is no water to be removed by evaporation in summer. In winter when dry winds are blowing off desert surfaces the evaporation is high and drying may be very rapid after rain. Even so, a rainfall of 4 or 5 inches in a month is bound to take some time to remove, particularly when winds are blowing from the sea.

3. In a monsoonal climate, such as Burma or Assam, the rainfall in the wet months is far too great to be removed by evaporation, but in the drier months a heavy storm is soon dried up, and vapour may be seen steaming off the ground in the intense tropical sunshine.

4. It may be added that evaporation from mud is a much slower process than evaporation from soil in good tilths. Hence the importance of restoring to tilth a soil that has become muddy, and of limiting the use of bare soil after rainfall if it is required to dry out quickly.

#### SECTION 28.—WET AND DRY SPELLS

1. The prevalence of wet or dry spells will call for study, chiefly for determining the suitability of different surfacing and drainage methods. In S.E. England, for instance, the monthly rainfall is fairly uniform throughout the year, but the winter months are marked by long spells of only moderately wet weather, spring and autumn by long spells of dry weather and the three summer months hold the expectation of heavy rains up to 2 inches in two or three days, with long intervening spells of little precipitation and heavy evaporation. The prospects in other regions can be similarly analyzed for general guidance.

2. The number of rain-days per month may be a useful figure. Records are based on different data in different countries and are not safely comparable. In S.E. England 155 days with not less than .01 inch of rain are recorded annually, 110 days with over 0.04 inch, and only 10 days with over 0.05 inch.

## SECTION 29.—MAXIMUM INTENSITY

1. Figures showing highest rainfall rate for a short time—the storm intensity—are required primarily for drain and pipe calculations. Intensity is expressed in inches per hour for some specified duration, and can often be deduced from daily or even monthly records with sufficient reliability for working purposes, when climatic characteristics are known. The following tabulation is illustrative of expectations during a wet year :—

Table IV.—Rainfall expectations during wet year  
(approximations only)

Place	Wet year's rainfall. ins.	Highest monthly rainfall. ins.	Highest daily rainfall. ins.	Maximum intensity of rainfall—inches per hour for one hour duration. (Estimated).
England, S.E. ...	30	5.0	2.0	1.0
England (Borrowdale) ...	130	20.0	4.5	2.0
France (Arras) ...	30	6.0	3.0	1.0
N. Italy ...	50	10.0	6.0	2.0
S. Sicily ...	40	12.0	8.0	1.0
Algiers ...	40	11.0	6.0	1.0
Palestine (Ramleh) ...	35	12.0	5.0	1.0
Libya ...	15	8.0	4.0	1.0
Assam (Srimangal) ...	125	34.0	8.0	2.0

2. In practice, the daily figure may be used for drainage calculations, whilst the figure for maximum intensity is useful to indicate the chances of temporary flooding, if a storm occurs, when free storage capacity of the drainage system is low, because of preceding rains.

## SECTION 30.—TEMPERATURE, HUMIDITY, AND PRESSURE

1. In some tropical and desert regions and at high altitudes, it is necessary to study pressure and temperature values to determine how much the standard runway lengths should be increased to allow for variation in atmosphere density.

2. In regions of great heat and humidity, it is obvious that special provisions may have to be made in the design of technical accommodation, rest rooms for pilots in readiness, shelters for maintenance parties, etc., apart from special requirements in design of domestic accommodation.

## SECTION 31.—MIST AND FOG

When there is scope for choice, areas with bad mist records must be avoided. In any case, expectations should be reported. Valley ground, sheltered from wind harbours mist, which is often of local occurrence along the low banks of rivers or on swamps. The main cause of mist is the big difference between day and night temperature, affecting

humid air. The smoke and fog of industrial areas rarely call for consideration under operational conditions abroad, but the desirability of windward siting should go on record.

### SECTION 32.—WIND RECORDS

1. Where station records are adequate, the frequency of different winds of high and low velocities, and of calms, is shown upon a Vector diagram called a Windrose. The purpose of this diagram is to show:—

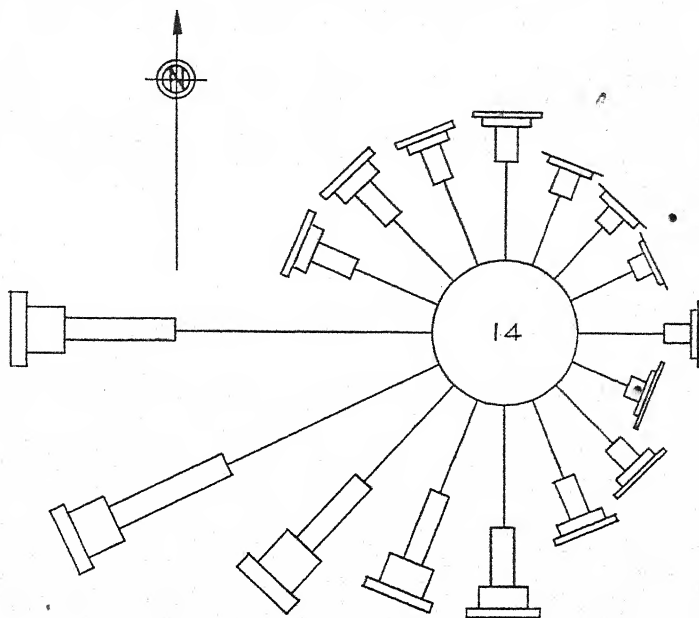
- (a) The direction from which moderate or strong winds blow, since by that means the best direction is given for orientating a single runway. It may be noted that to decide the best direction the frequencies of N. and S. winds should be added, N.E. and S.W., E. and W., and S.E. and N.W. as is shown in the inset to Plate 11.
- (b) Whether a second runway is important and, if so, its most effective direction.
- (c) The probable proportion of time during which the runways so designed could not be used.

2. For reliable interpretation, it is necessary to have hourly observations made over a number of years and analysed to each Beaufort force, to 16 points of the compass. Such detailed data are not usually available. Windroses are as a rule only obtainable with 8 points, and interpolation may be required to decide the best runway direction.

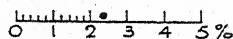
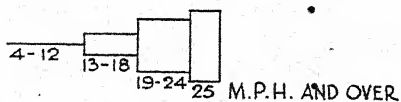
3. A cross-wind, of considerable frequency, is acceptable if its component, normal to any available runway, is not in excess of 10 miles per hour. For operational conditions and for heavy aircraft, a component of 15 miles per hour is commonly accepted. For example, permissible cross-winds would range as follows:—

				<i>For 10 m.p.h. component</i>	<i>For 15 m.p.h. component</i>
At 60 degrees	...	...	...	11.5 m.p.h.	17 m.p.h.
At 45 degrees	...	...	...	14 m.p.h.	21 m.p.h.
At 30 degrees	...	...	...	20 m.p.h.	30 m.p.h.
At 22½ degrees	...	...	...	26 m.p.h.	39 m.p.h.

4. Two typical Windroses are shown in Plates 10 and 11. The first is for an important station in England, with full data for 16 compass points. The second is representative of requirements in operational areas, giving frequencies of winds, for 8 compass points, in three groups of wind force only, 1 to 12 m.p.h., 13 to 38 m.p.h., 39 m.p.h. and over. Conditions may demand separate Windroses for different seasons, or for day and for night. The grouping of velocities is governed by local wind behaviour.



### SCALES



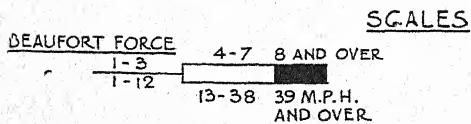
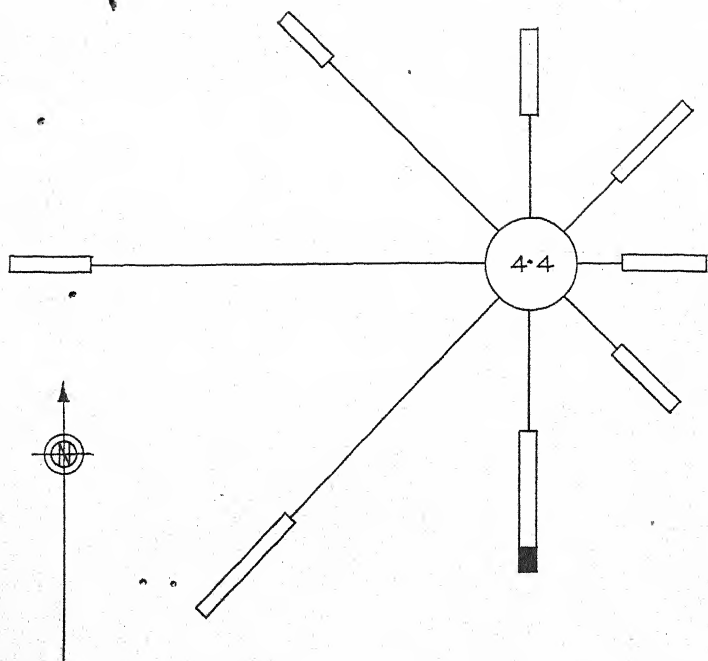
### B. FORCE

2+3 4 5 6 AND OVER

PERCENTAGE FREQUENCY OF WINDS EXCEEDING 12 M.P.H.  
(FORCE 4 AND OVER)

N+S 3.8	NNE+SSW 4.3	NE+SW 4.8	ENE+WSW 5.7
E+W 5.4	ESE+WNW 2.4	SE+NW 2.9	SSE+NNW 3.0

PLATE 10.—TYPICAL 16-POINT WINDROSE FOR STATIC  
AERODROME. SOUTH EAST ENGLAND—  
FOUR FREQUENCIES



PERCENTAGE FREQUENCY OF WINDS EXCEEDING 12 M.P.H.  
(FORCE 4 AND OVER)

N+S  
10.0

NE+SW  
10.4

E+W  
7.4

SE+NW  
6.5

PLATE 11.—TYPICAL 8-POINT OPERATIONAL WINDROSE  
—THREE FREQUENCIES

5. The Beaufort scale of wind force is the accepted standard. The specifications are formulated for observers without apparatus for measuring velocities.

Table V.—Beaufort Scale of Wind Force

Beaufort scale No.	General description of winds	Specification of scale	Limits of velocity m.p.h.
0	Calm ...	Smoke rises vertically ...	Less than 1
1	Light air ...	Wind direction shown by smoke drift, but not by wind vanes.	1-3
2	Slight breeze ...	Wind felt on face; leaves rustle; or- dinary vane turned by wind.	4-7
3	Gentle breeze ...	Leaves and small twigs in constant motion.	8-12
4	Moderate breeze	Raises dust and loose paper; small branches moved.	13-18
5	Fresh breeze ...	Small trees in leaf begin to sway ...	19-24
6	Strong breeze...	Large branches in motion; whistling in telegraph wires.	25-31
7	High wind ...	Whole trees in motion ...	32-38
8	Gale ...	Breaks twigs off trees; generally im- pedes progress.	39-46
9	Strong gale ...	Slight structural damage occurs; chim- ney pots removed.	47-54
10	Whole gale ...	Trees uprooted ...	55-63
11	Storm ...	Widespread damage ...	64-75
12	Hurricane ...	... ..	Above 75

### SECTION 33.—DAY AND NIGHT WINDS

1. On the whole, winds are stronger and more gusty by day, lighter and steadier at night. It may often be noticed for instance even in England how the wind is felt to get up some two or three hours after sunrise, and to lull at night. The effect is more marked in summer than in winter, and is much more marked in lower than in higher latitudes.

2. The lulling of the wind at night is associated with the cooling of the ground (and lower layers of the air), which occurs particularly when night skies are clear. The rising of the wind by day is associated with the warming of the ground by the direct (or scattered) radiation from the sun, and so occurs particularly when the daytime skies are clear or have become full of broken cumulus cloud.

3. It should be noted that the cooling of the lowest layers under clear skies at night is likely to lead to an "inversion" of temperature, and indeed it is the formation of the inversion which produces the lulling of the wind at night. But the cooling of the lowest layers and the formation of an inversion are both agents which favour fog formation. So places which are found to have a pronounced lull at night may be also places where night visibilities are frequently poor.

### SECTION 34.—DUST STORMS

1. In desert countries or where a summer-dry climate prevails, the incidence of dust storms will often be of great significance in relation to visibility and aircraft maintenance.

2. The efficiency of the wind as a dust raiser is affected by velocity, turbulence, plant-growth, temperature, humidity, and the available reserves of free dust. Where uncompacted dry sand or silt is very fine, a wind velocity of over 12 miles per hour may be very troublesome. In a high wind, the sun becomes invisible and aircraft cannot take off.

3. Where dust is raised by operational aircraft taking off from a natural strip, the pall of dust which hangs over the ground when there is no wind, may prove an important factor in layout design.

If there is much traffic in the neighbourhood of an airfield in a dry climate, it may be necessary to divert traffic to the leeward side of the airfield so as to prevent interference with aircraft from dust.

## CHAPTER 4

### AIRFIELD RECONNAISSANCE

#### SECTION 35.—GENERAL

1. The selection of favourable areas for airfield sites is commonly based upon a study of maps, intelligence reports and air photographs, supported by the observations of an engineer and an air force officer flying over the ground. Observations are made from high altitudes until comparatively small areas have been selected for more intensive observation in slow-speed aircraft flying close to the ground. Air photographs and air reconnaissance assist greatly, but very rarely obviate the necessity for a thorough reconnaissance on the ground. Slopes and undulations although beyond permissible limits, may be too small for determination, even by precise stereoscopic methods.

2. Soil characteristics will rarely be determined with sufficient accuracy from indirect sources of information, or by deduction from ecological data.

#### SECTION 36.—PRELIMINARY GROUND RECONNAISSANCE

1. The preliminary examination of favourable areas is sometimes undertaken by officers of a field company in the course of a general engineer reconnaissance. This task is dealt with in the R.E. Reconnaissance Pocket Book, 1944. Valuable information is often gained, at the earliest juncture, by engineer troops with a leading brigade or division. For this reason it is desirable that the reconnaissance party of the airfield construction group should travel with the forward brigade.

2. The responsibility for selection falls on the reconnaissance parties of airfield construction groups, upon whose reports, to the Chief Engineer, the A.O.C's decision will largely be based. The critical assessment of time and resources required to bring a landing ground to an acceptable state of serviceability carries most weight when made by the engineer command called upon for the fulfilment of that estimate.

3. "Standard" questionnaire and report forms, compiled for universal use, comprise a useful *aide memoire*, but they generally contain many inappropriate items, tending to divert attention from the few particular features which will have a dominating influence upon decisions. Special instructions, relative to a particular terrain, will always be required to prevent waste of time and effort.

4. In offensive operations, the choice of sites is generally restricted. Physical conditions are often well known in advance. Ground reconnaissance will be necessary to determine if there are special difficulties or adverse features, not previously disclosed by air photographs and air reconnaissance, and to review provisional estimates of time and resources for construction.

5. The crucial points for investigation will be :—

- (a) Slopes and undulations.
- (b) Characteristics of soil, for natural surfacing or as a foundation for available types of runway mat.
- (c) Facilities for taxi-tracks and dispersal areas.
- (d) Condition of access roads or tracks, and proposals for future requirements.
- (e) Flying-approach obstructions in detail.
- (f) Local materials.—These may be important, especially for drainage, but projects must envisage completion of surfacing without much initial help from chance resources.
- (g) General characteristics, beyond those essential for the short-term view, to be covered if time allows. Certain specific problems—probably one or two—will need intensive investigation.

6. Hasty reconnaissance calls for the exercise of quick individual judgment, based upon wide knowledge and experience of the behaviour of different soils, of the capacity of mechanical equipment and of the standard of results to be considered passable in terms of the Air Force "brief". Few hours will be allowed for the task.

### SECTION 37.—DETAILED RECONNAISSANCE

1. Deliberate reconnaissance, preceding more permanent types of construction, or following the selection of and start of work on advanced landing grounds, will involve an exhaustive investigation of many other engineering and aeronautical factors.

The problem may concern the relative merits of alternative sites or the opportunities for major expansion. Compared with the conditions of a hasty operational reconnaissance, individual difficulties and responsibility are often less exacting because the chances are better for detailed examination and check, for guidance from laboratory tests, and for discussion with specialist and other officers.

2. Selection of sites and estimates of work can be made only with a full appreciation of Air Force "standards", and of all practicable methods of construction, suitable for the soil characteristics determined in the field. The questions demanding special consideration in any particular reconnaissance will rarely be in doubt against this background of knowledge and experience.

3. All the significant points which may call for attention either in hasty or in deliberate reconnaissance are enumerated below under two main headings, "Sketch plan" and "Airfield reconnaissance report."

4. **Sketch plan.**—Nearly always of first importance, especially where doubts arise as to the feasibility of construction or suitability of location, is the production of a handy sketch plan on a scale of about 1 : 10,000. This plan must show, in words or graphically :—

- (a) Recommended name or designation of landing ground, preferably the name of nearest town or village marked on small-scale maps. If there is likely to be a group of airfields, the suffix main, east, west, etc., can be used (to indicate inter-relationship of airfields) with due regard to probabilities of further construction.  
It is better to have a group of airfields firmly named from the start than to change designations later, even for a more rational system. Changes of name, like changes of technical terms, lead to confusion without adequate benefit. Decision on names is given by the R.A.F.
- (b) Type of aircraft to be served.
- (c) Map sheet reference, with latitude and longitude, and grid lines if possible.
- (d) Compass points, with an arrow showing the accepted prevailing wind (from meteorological information and observations in the field).
- (e) Height above sea-level.
- (f) Scales, proportional and natural.
- (g) Prominent local features for easy recognition from the air, such as cairn, farmhouse, pond, copse, windmill, etc.
- (h) Obstructions.—Show all potential flying obstructions, indicating by arrow any distant hills or other features outside the boundaries of the plan. If obstructions are a serious factor of uncertainty, a special sketch-plan, with section drawings, may be necessary to assist the R.A.F. in making their decisions. All obstructions over 100 feet high within a radius of two miles should be marked.
- (i) Contours.—Main contours taken from large-scale maps, with any interpolation demanded by local conditions.
- (j) Landing strips.—Suggested layout in full lines. Corner points will be marked by stakes in the ground, but these points should be fixed on the map, in case of change, by bearing lines and distances from suitable stations.
- (k) Maximum extensions practicable for width or length. Show in broken lines.
- (l) Adverse features.—Soft patches, rock outcrops, hummocks, gullies, etc.
- (m) Main communications.—Existing road and rail, with neighbouring place names and distances.
- (n) Access communications.
  - (i) Existing access tracks, showing best lorry route.
  - (ii) Proposed additional access tracks for service of airfield.
  - (iii) Dispersal areas proposed.
- (o) Drainage.—Outfall channels, natural or artificial.
- (p) Plant life, showing orchards, crops, timber growth, etc.
- (q) Proposed camp sites and mechanical equipment park,
- (r) Officer's name and date of reconnaissance.

**5. Airfield reconnaissance report.**—In addition to the above sketch plan, covering first essentials, a report must be written, dealing with any of the following points which may be relevant to the situation :—

(a) *Meteorological conditions*

- (i) Prevailing and other important winds, at different seasons.
- (ii) Rains. Dust storms.
- (iii) Fog. Mist. Low cloud.

(b) *Surface conditions : soil and sub-soil*

- (i) Soil classification in terms of gravel, sand, silt, loam, clay, organic type.
- (ii) Permeability.
- (iii) Compaction characteristics.
- (iv) Other important soil features.
- (v) Evidence of vehicle tracks, current and old, in relation to bearing capacity of soil and sub-soil.
- (vi) Vegetation—natural and cultivated.
- (vii) Rough, stony, or soft patches.
- (viii) Rock outcrops.

(Pits to be dug and samples of soil and sub-soil to be taken.)

(c) *Gradients.*—(Notes or sketches in amplification of data shown on sketch plan.)

- (i) Gradients in relation to strips, taxi-tracks and drainage.
- (ii) Average over-all gradient and direction of slope.
- (iii) Details of any gradient exceeding 1 in 80.
- (iv) Undulations.

(d) *Drainage*

- (i) Depth of water-table, maximum and minimum.
- (ii) Condition of soil after rain. Run-off and infiltration.
- (iii) Details of main outfall channels to serve future drainage.
- (iv) Any evidence of flooding in area.

(e) *Flying conditions*

- (i) Description of flying approaches within one mile of strips in all directions.
- (ii) Hills within five miles.
- (iii) Nature and position of obstructions in approach zone.  
Magnitude of task of removal.
- (iv) Any ridge or scarp liable to cause wind turbulence.

(f) *Communications.*—Amplification of essentials shown on sketch plan.

(g) *Local resources*

- (i) Stone quarries, broken stone, bricks, gravel, sand (giving physical condition and rough grain sizing), cement, aggregate, piping, empty drums, etc.
- (ii) Water both for construction and for potable supply.
- (iii) Any accommodation for offices, headquarters, operations, signals, etc., whether ready for occupation or needing repairs.

*(h) Construction*

- (i) Brief outline of work required to prepare strips for service in dry weather, and wet weather. Also to clear ground outside strips.
- (ii) Conditions for enlargement of strips, in length and width.
- (iii) Requirements in personnel, plant and transport with special reference to most urgent initial tasks.
- (iv) Estimated time required, with above resources, to complete work in such stages as fit the situation; *e.g.*, first task, one landing lane 1,200 by 40 yards, with dispersal for 20 aircraft.

*(i) Camouflage*

- (i) Opportunities for concealment of aircraft and dumps should be stated. (Good dispersal facilities are generally of greater importance.)
- (ii) State if there are any conspicuous landmarks which make location of landing ground easy for enemy bombers.

*(j) Relative merits of alternative sites.*—In the case of selecting a site within a wide favourable area, the officer responsible should indicate the limits of the area which he has examined. An inferior site will be sometimes developed, whilst a better site, beyond the area covered, is missed for shortage of time on reconnaissance.

*(k) Opportunities for expansion.*—The opportunities presented by a site for expansion and development into a bomber airfield, are rarely a factor of any importance in choice of landing grounds for a tactical air force, but should be recorded if clearly established.

*(l) Hygiene.*—Health factors, with particular reference to standing water and proximity of habitations in a suspected malarial zone.

## CHAPTER 5

## AIRFIELD SURVEYS

## SECTION 38.—GENERAL

Airfield surveys are of four types :—

- (a) Air.
- (b) Topographical.
- (c) Construction and quantity.
- (d) Soil.

## SECTION 39.—AIR SURVEY

1. Air photographs are required to record the general character of a site, and are valuable in support of subsequent topographical and soil surveys. Heights and gradients may, in favourable circumstances, be judged with sufficient accuracy for comparison of different sites. Topographical maps compiled from air photographs have the great merit of assured, detailed accuracy at date.

Air photographs are indispensable as a basis for discussion of camouflage problems.

2. Some or all of the following should be used for planning :—

- (a) A photographic mosaic made up from vertical air photographs, and stereoscopic pairs of the prints used in its compilation. The mosaic should cover the whole airfield region, including a mile or two beyond the site for development. Scale 1 : 10,000.
  - (b) Oblique photographs from four points of the compass, taken at an altitude of 3,000 feet, at a distance of about one mile, with the standard 8-inch F.24 type camera.
  - (c) For intensive camouflage study, coloured photographs would be desirable. Excellent photographs have been taken in America, but these are best when large-scale pictures can be taken at a low altitude in good atmosphere.
  - (d) Approach photographs taken at not less than 20,000 feet and five miles distance are needed to illustrate the field as it would appear to approaching enemy bombers.
  - (e) Special stereoscopic pairs on a scale of 1 : 5,000 or larger, may be required of important sections.
3. The most refined methods do not obviate the necessity for final examination on the ground, but the use of the stereoscope is important even though relief is not being examined. The fused image is always better than the single picture.

#### SECTION 40.—TOPOGRAPHICAL SURVEY

1. The need for detail in a topographical map of the area is governed by many variable factors.

- (a) Assuming a heavy programme of work and broken terrain, an accurate map on a scale of 1 : 2,500 (minimum 1 : 5,000) is required, with contours at 2 feet to 10 feet vertical interval. A carefully adjusted layout of permanent runways and tracks may effect important economies in cut and fill; the latter process being particularly undesirable in runway work. The invariable demand for maximum speed of completion should stimulate thoroughness of survey rather than any scamping of preliminary mapping and estimate.
- (b) In regions of intense vegetation, a number of survey lanes may have to be cut through heavy growth before decisions can be reached with adequate assurance.

2. Survey requirements for important work in comparatively irregular country, may be summarized as under :—

- (a) Levels for centre lines, edges of runways, edges of shoulders or flight strips; lines 100 yards right and left of centre line; lines through any points showing change of gradient. The level lines should extend 200 yards beyond end of runway or strip in each direction.
- (b) Levels through drainage depressions.
- (c) Levels where other physical features demand, within perimeter of airfield.
- (d) A grid of levels, at 100-yard intervals, to cover dispersal and other occupied areas.

- (e) Field notes—giving traverses of centre lines and magnetic bearings. Traverse lines should be carried from strips to the property or natural boundaries defining the perimeter of the airfield.

Traverses of drainage depressions should allow catchment areas and capacities to be computed in the light of probable run-off, after allowing for infiltration and the effects of observed vegetation.

3. Survey instruments.—Requirements are :—

Prismatic compasses (2).	Dumpy levels (2).
Abney level, Mark 4.	Staves, levelling (4).
Measuring tapes (4).	Theodolite, 3½-in.
Pegs, 8-in. and mallets	Plane table.
Ranging rods, 6-ft., with flags.	Matchets.

4. For all hasty reconnaissance, prismatic compasses and Abney levels are sufficiently accurate. A gradient of 1 in 60 is equivalent to 1 degree. The Abney can be read with a probable error of plus or minus 5 minutes. Major distances can be determined by checked readings on the speedometer.

5. The survey party should include two officers, three N.C.Os. and a number of other ranks according to requirements for subsidiary work.

#### SECTION 41.—CONSTRUCTION AND QUANTITY SURVEYS

1. No special practice is involved in quantity surveying and marking out for airfield tasks. It is only necessary to emphasize the significance of accuracy in a task of the great magnitude of a fully equipped airfield, with permanent surfaces, over which an inch of thickness may represent 10,000–20,000 tons of sand or stone.

2. Even in hasty construction, commonly a problem of area rather than volume, a good standard of accuracy in the calculation of subsidiary cut and fill is particularly important, when earth-moving plant is in short supply.

#### SECTION 42.—SOIL SURVEYS

1. In war, soil investigations fall into three distinct categories :—

- (a) Study of inaccessible ground by means of topographical, geological, and soil maps, official records, and intelligence reports, supported by air photographs and direct observation from the air.
- (b) Hasty ground surveys, as a factor in reconnaissance for advanced landing grounds, when engineering risks are justified by short-term considerations, and when field methods of determination, with little equipment, will be adequate.

- (c) Exhaustive or confirmatory surveys, conducted with the aid of field or central laboratory staff, to present a full picture of probable characteristics, under all conditions of weather, service and treatment, whatever the future role of the airfield may be.

2. Ground surveys under para. 1 (b) and (c) above will include the reconnaissance and testing of adjacent soil deposits of potential value as materials in the improvement of natural surfaces or in the construction of base and surface courses.

The ground water-level, normal and highest, calls for investigation in nearly all circumstances.

#### SECTION 43.—SOIL SURVEY METHODS

1. R.E. mobile laboratory units have been organized to give the earliest possible guidance upon the characteristics or quality of soils, stone, cement and other materials.

2. Laboratory vehicles can function fully within an hour of reaching a site. As a rule, they will be employed centrally to serve a number of tasks. The following equipment is carried :—

##### (a) Laboratory

Proctor optimum moisture-density apparatus  
 Permeability test apparatus  
 Liquid limit apparatus  
 Field density apparatus  
 Viscometer  
 Penetrometer  
 Hydrometers  
 Balances, sieves, and other miscellaneous laboratory equipment  
 Boxes about 15 inches cube to carry sample tins  
 Sample tins for field and laboratory

##### (b) Instruments

Theodolite (rarely needed)  
 Level and staff  
 100 ft. steel tape and 100 ft. cloth tape  
 Ranging rods, pegs, books, etc.

##### (c) Tools

2 Post-hole augers with extensions and tommy bars  
 1 Gravel auger  
 1 Auger with self-closing flaps  
 1 Twist auger for cohesive soils  
 1 Crowbar for connection with auger extensions  
 Spades, shovels, picks, statulas and survey stationery

3. **Survey procedure.**—In hasty reconnaissance, only a few critical samples of surface soil and sub-soil will be taken. Before important works are undertaken it will be necessary to subject the soil to close examination. Methods described below are based on the recommendations of the Road Research Laboratory, England.

(a) **Equipment.**—A 10-cwt. van is wanted for personnel, equipment and samples. Tins for soil samples should be air-tight. Except for gravelly soils, a 1½-lb. sample is sufficient for identification tests.

- (b) *Sampling*.—Samples may be taken with a 4-ins. or 5-ins. post-hole auger. On stony ground a gravel-auger or crowbar will be needed. Augers and extension pieces should be made an exact number of feet in length. For shallow work, test pits are more satisfactory than auger holes.

At least one sample is taken from each different layer penetrated. Depth of holes is normally four feet, giving two or more samples, reduced by quartering to the size required.

- (c) *Siting of holes*.—An area must be covered by a grid, and landing strips by a single or double row of holes. Distances apart of holes will vary from 1,000 feet to 100 feet, depending on the urgency of precision and the soil conditions. Maps on a scale of 1 : 2,500 and 1 : 10,000 will be used for plotting.

- (d) *Records*.—Full records must be kept, on boring record sheets, for identifying and describing samples. The general description should give the nature of the ground, *e.g.*, ploughed land ; the depth of foreign matter cleared off before boring ; prevalence of stones ; details of soil as to colour, texture, consistence and structure.

4. **Soil profile**.—The most important record based on data obtained by survey and laboratory test is the profile, showing the character and disposition of soil layers, and the water table if shallow. Profile sheets are developed in the field as work progresses, so that apparent abnormalities can be confirmed or corrected on the spot. Subsequently the results of tests are added, so that profiles and plan present the full record of conditions affecting projects of construction.

Suitable scales for profile sheets are *Horizontal* 1/2,500 ; *Vertical* 1 inch equals 5 or 10 feet, depending on topography.

#### SECTION 44.—EVIDENCE OF MAPS, RECORDS AND AIR PHOTOGRAPHS

1. Planning staffs are able to gain valuable guidance as to probable soil conditions, upon which estimated requirements of stores and equipment may be largely based, by the scrutiny of air photographs.

Only a few, of the necessary scientific training, can be proficient in this work, but airfield construction officers are often called upon to fly over strange country on reconnaissance or to give an opinion of air-photographic evidence in the field. They should extend their knowledge of interpretative methods as far as practicable.

2. A few of the simpler features calling for identification may be given by way of example.

- (a) *Colours*, and particularly colour changes which indicate the position of soil-type boundaries, are often significant. Colour and moisture content are closely related. Air photographs taken at known intervals after rain may provide valuable information as to the behaviour of soil. In the tropics red soils are as a rule fairly well drained.

- (b) *Loams and clays* are generally incapable of differentiation without contributory evidence from plant-life. Sometimes, however, clays are characterized by drainage features. The absence of streams in flat terrain generally indicates that the rainfall is largely absorbed by the soil, with little or no surface run-off.
- (c) *Dune sand* is easily recognizable by its cloudy appearance on air photographs. Hills of half-moon shape imply soil of wind-blown origin, and the axis indicates the direction of the prevailing wind. Erosion features will differentiate between sand and loess. Erosion slopes in "clean" sandy soil are similar to the angle of repose of sand heaps. Loess, on the other hand, is characterized by steep erosion banks.
- (d) *Sand* in general is recognizable by its lighter colour, but not all sands are whitish or yellow, and many calcareous soils of finer type show similar light shades. *Marshes or swamps*, in the desert, have a jelly-like appearance in air photographs, and salt is sometimes discernible at the edges in white incrustations.
- (e) *Drainage*.—The different types of drainage pattern in any one region are closely related to topography and soil type. A stream meandering across an area indicates that the general drainage area is flat to gently undulating, that the soil has a fairly heavy texture, and that surface run-off dominates drainage. The absence of such streams in flat terrain generally means that the rainfall is largely absorbed by the soil, with little or no run-off; hence the soil promises to be well drained and favourable for airfield construction.

#### SECTION 45.—ECOLOGICAL DATA

1. With the advance of aerial photography and survey in the last 20 years, the ecological relationship between types of vegetation (including variations in visibility and disposition) and of rock and soil characteristics, has been more effectively studied. The application of ecological principles can be reduced to narrow limits as soon as characteristic combinations of climate, geology, topography and vegetation have been established.

2. If the vegetable growth is natural or semi-natural, the differences in soil within a region are generally reflected by the plant-types. Although extended human occupation and cultivation of a region will, in some cases, have obscured such natural distinctions, in other cases the artificial boundaries, created by the selective cultivation of different soil-types or by drainage conditions, will give distinctive evidence. In illustration the following examples are given:—

- (a) Plum and apple orchards are usually on heavy loam or clay-loam, rarely on light well-drained sandy soils.
- (b) Extensive areas of flat land in grass indicate either poor or heavy soils, not in the range from sandy to sandy loam unless ground water table is high.

- (c) Citrus is generally planted on loamy or clayey sands in Palestine and E. Cyprus, but elsewhere (e.g., Sicily) loamy soils are used. Seldom, however, is citrus planted on sand and never on heavy clay.
- (d) Olives are seldom found on sand, and never on clay in Palestine, Syria, or Cyprus. More often, they are planted on shallow calcareous and rocky ground, whereas the heavier and deeper soils are reserved for grain.
- (e) In summer-dry Mediterranean countries, grain is never sown on sandy soils because of their low water-holding capacity. This is not the case further north where a more even rainfall distribution compensates for this deficiency.
- (f) In the desert, scrub indicates a silty sand, or in Italy an impervious red clay ("barragge").
- (g) Cotton may indicate the notorious "cotton-soil," badly drained silty clay, readily serviceable in the dry season and extremely difficult to deal with in the wet.
- (h) Rushes and willows establish a high water level, which prevents, by drowning of roots, the cultivation of fruit or grain.
- (i) Bracken and gorse favour a well-drained soil.
- (j) In the East, rice is associated with seasonal flooding and an underlay of hardpan.
- (k) Wheat usually indicates non-slaking clay.
- (l) Bare land in the midst of cultivation may denote slaking clay or seasonal flooding; in arid districts, the presence of some troublesome alkali.

3. Generally speaking, in summer-dry districts, striking differences in vegetation are associated with differences in soil types. In districts of more evenly distributed rainfall, vegetative distinctions are less pronounced, and in very humid regions may be almost indeterminable.

#### SECTION 46.—ENGINEER REPORTS AND MAPS

1. No standard form of engineer progress report, covering all types of construction will be satisfactory. Skeleton forms will be compiled by the responsible engineer formation or unit, appropriate to the physical conditions and urgency of the task, and the opportunities for close recording of progress without waste of time and effort. Standardization of reports within an area where methods are comparable is, however, of obvious importance.

It is a constant engineer responsibility to report progress of work, clearly and speedily, and to record results in some simple form for Air Force formations and Army staffs.

2. Rapid collection and distribution of information, during an advance, can be most satisfactorily effected by means of key maps, on a scale of about 1:500,000. Upon the margins of these maps, up-to-date replaceable panels of airfield plans, on a scale of about 1:100,000, are affixed.

Panels should show all essential features of completed runways, strips, taxi-tracks, dispersal, servicing facilities, and accommodation. Outside terrain should be covered for about 1 kilo beyond the area of construction.

Amendments and additions, shown on new panels, are distributed promptly to the holders of maps, for sticking over the outdated inset maps. A specimen of such operational engineer maps, for adaptation to local needs, is given in Plate 12.

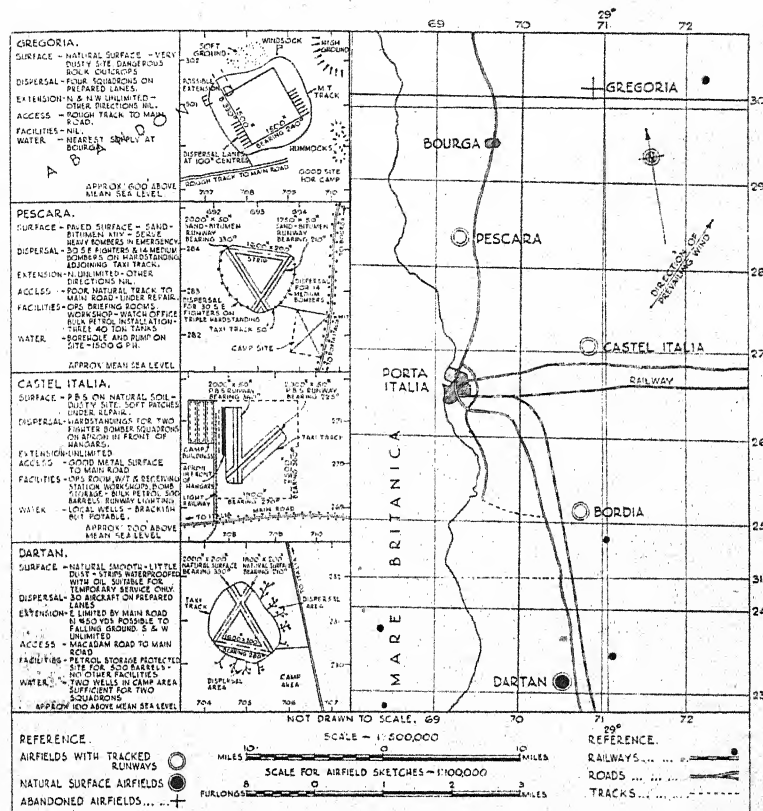


PLATE 12.—TYPICAL AIRFIELD MAP WITH PANELS

3. Detailed tabulations, giving the particulars of each airfield, may also be required for despatch to higher formations and for permanent records, but the graphic method is more serviceable in operations, when heavy paper-work is urgently avoided. Schedules are difficult to amend for individual items, and the re-issue of complete new sets, for the large number of airfields covered in an army area, is likely to be too infrequent to meet exacting demands for current accuracy.

4. The graphic representation appeals particularly to air staffs and operational units. Airfields are so large and far apart, that their location can be reliably indicated upon 1 : 500,000 key maps of rough draughtsmanship without fear or any confusion of identity.

## CHAPTER 6

## DRAINAGE OF AIRFIELDS

## SECTION 47.—INTRODUCTION

1. The technical problems of airfield drainage are often the most pressing and complex with which the engineer has to deal. The constants are few and the many variables are generally difficult to assess. The correct interpretation of soil and other physical conditions, and the adoption of suitable drainage methods, may be essential for the continued serviceability of a field. Skilful work, or the avoidance of needless elaboration, will always be profitable.

2. The engineer must know his job. He must be confident in his decisions, not only to attain success and economize resources, but in order to convince those who may be asked to meet unwelcome demands at the expense of other tasks of more obvious urgency. He obtains a high priority when he calls for transport, equipment, and materials directly contributing to the creation of runway or dispersal areas. Less support may be forthcoming for protective measures against the ill effects of rainfall seepage or a rising water table.

3. The geologic origin of the wide flats necessary for the successful siting of big airfields, is commonly associated with unfavourable water characteristics. The absence of heavy undulations and erosion channels connotes poor run-off, whilst highly permeable soils are generally unstable. Low-lying areas which present the most favourable features from the flying and rapid surfacing aspect, will often form a natural repository for water from higher ground.

4. It is common experience to have to make drainage schemes conform to some predetermined layout, in the pattern of which the drainage features play small part. In war, the first demand is for speed in construction of landing and dispersal facilities, where flying considerations are good or passable, and locations are tactically suitable. The risk of future unserviceability, due to heavy storms or even normal rain, will often be accepted or ignored.

## SECTION 48.—GENERAL CONSIDERATIONS

1. In an operational area abroad, the main factors governing the drainage problem, upon a particular site, are the following:—

- (a) Topographical features, with special reference to contours and natural drainage within the airfield area. Drainage systems must be considered in relation to the natural drainage of the area and be designed to fit into it. Interference with the natural drainage of an airfield is a common source of trouble.
- (b) Rainfall probabilities, expressed in seasonal distribution and storm intensities.
- (c) Soil characteristics, disclosed by survey profiles, analysis, and observation.
- (d) The water-table (surface of a subterranean lake) and its seasonal changes of level.
- (e) Time and facilities available for work and the degree of immunity from flood-risk demanded operationally.

2. The drainage system must be laid out in order to remove all surface water from the operating areas, as rapidly as possible, without causing erosion. Standing water, even outside the runways and taxi-tracks, is a direct menace to aircraft and, if allowed to remain, may lead to detrimental softening of border strips or of track sub-soil. Water lying on paved surfaces is a menace to pilots, blinding their wind-screens or even damaging their flaps.

3. Types and dispositions disclosed by the soil profiles influencing layout and methods of drainage, are as follows :—

- (a) *Uniform and pervious soil.*—With such favourable conditions, not often found, artificial drainage may be wholly unnecessary.
- (b) *Uniform and impervious soil.*—This condition is common. It becomes urgent to remove runway water as soon as possible, but sub-drainage is unlikely to be needed. The clay-loam or "cotton-soil" group of soils, so prevalent in summer-dry regions of the Mediterranean, fall into this class. Such soils become practically impervious after the filling of cracks and saturation by the early winter rains.
- (c) *Pervious soil above and impervious below.*—These conditions may demand sub-drains just above the impervious layer, unless it is deep enough to cause no trouble.
- (d) *Impervious soil above and pervious below.*—This condition may be met by surface drains cut through a thin top layer. If this top layer is very thick, the existence of the permeable soil below may have no practical importance.
- (e) *Irregular disposition of pervious and impervious beds.*—Irregular deposits can only be dealt with in the light of the ascertained conditions. Such deposits may well be the most troublesome type and call urgently for sub-drainage, especially where heavy frosts prevail.

4. A commonly adopted target in the design of drainage systems upon military airfields is the removal in three hours of (a) the maximum rainfall to be expected in one hour, or (b) the normal daily rainfall. Rainfall intensity figures, for many regions, show such extreme variations that only the expectation of serious danger or loss of service from flooding, would justify full measures against the results of abnormal storms.

A storm assumption in excess of average expectations would be justified only as a safety factor. But however accurate this rainfall estimate, all calculations based upon it are liable to be highly conjectural, as applied to the capacity of drains and pipes hastily installed under war conditions.

Lacking data for rain intensity at specific localities in regions where the annual figures are known, acceptable assumptions of drainage capacity requirements can be made by deduction. In countries with sharp seasonal variations, as in North Africa and the East, a single day's rain will normally vary from 5 per cent. of the annual figure, where precipitation is moderate, to 10 per cent. for regions of heavy rain.

In England and Western Europe, with a higher number of rain-days of lower intensity, more evenly distributed throughout the year, these proportions are reversed. A safe assumption, without reference to any particular site, would be a single day's rain of 8 per cent. of the annual precipitation, where low rainfall prevails down to 4 per cent. for West Coast regions recording over 100 inches annually.

## SECTION 49.—RUN-OFF

1. Run-off plus percolation equals rainfall, the effects of evaporation and plant transpiration being of no account during storm periods. Percolation estimates will be heavily affected by the records of rainfall preceding the storm. At the beginning of a wet season or after a fine spell, percolation is great compared with subsequent phases when surface saturation retards the process. Run-off percentage increases with storm duration, for similar reasons.

The following table (U.S.A.) gives a picture of probabilities, which is wide enough for application to any other known conditions :—

Table VI.—Percentage of run-off under various conditions

Area type	Percentage of run-off	
	5-min. storm	2-hour storm
Runway or landing lane :—		
(a) Compacted soil	50%	90%
(b) Gravel or crushed stone	60%	100%
(c) P.S.P. over sand	25%	50%
(d) Bitumen surface	90%	100%
Apron or flight strip :—		
(a) Sand	20%	40%
(b) Loam	40%	60%
(c) Clay	60%	90%
Natural soil :—		
(a) Sand	20%	30%
(b) Loam	40%	60%
(c) Clay	60%	90%

The factors are based on a maximum 2 per cent. slope for natural surfaces. For steeper slopes, found outside the developed landing area, the run-off percentage should be increased by 2 per cent. for every increase of 2 degrees.

2. An illustration of the use of the above table, to determine run-off and consequent rate of discharge at critical points, may be given in the case of a P.S.P. crowned runway, 2,000 yards by 50 yards, upon compacted sand underlay or base course. It is required to deal with 2 inches of rain in two hours. Assume a drain on each side of the runway, in two lengths of 1,000 yards, graded toward the centre; a cross-drain under the runway and a main outlet channel collecting the total quantity.

The catchment area of the whole runway is 900,000 square feet. Assuming 40 per cent. run-off this gives 60,000 cubic feet of water in two hours, or 0.83 cubic feet per second or cusecs at the main outlet.

The capacity of each of the four lengths of side drain, collecting water from the runway and delivering to the transverse system, would require to be greater than 0.2 cusecs at its lower end, and the cross-drain greater than 0.4 cusecs; the main outlet would be designed to carry the total flow.

3. In developed areas, it is commonly possible to obtain direct evidence of maximum run-off by an examination of local water courses, natural or artificial, serving the flats before joining any storm-water

channels from higher ground. In undeveloped countries any area of flat ground big enough for airfield sites, without deep erosion channels, is likely to have a low run-off.

The important storm is the one that lasts long enough for water falling on the farthest portion of the runway to reach the outlet. Time of concentration is the essence of design of storm-water or sub-drainage of runways.

## SECTION 50.—SURFACE DRAINAGE

1. The two purposes of surface drainage, which may be of open or sub-drain type, are the rapid collection and removal of water falling on the operational surfaces, and the prevention of flooding by water which might flow from any source on to portions of the field in use.

2. At safe distances from the cleared areas or where they do not constitute the only obstacle, big open ditches can be advantageously employed, not only to intercept all ground and surface water and to act as outfall ditches, but also, at times, to assist in lowering the water-table, with good results upon soil stability throughout the airfield.

3. Generally speaking, military engineers are better equipped to undertake rapid work upon open ditches than for the production of materials for sub-drainage schemes. Difficulties commonly arise in the rapid provision of graded stone, piping, tiles, or improvised channelling. The utmost use should therefore be made of open designs consistent with safety, a policy followed with advantage by the U.S. Aviation Engineers in Mediterranean areas.

## SECTION 51.—SUB-SOIL DRAINAGE

1. Sub-soil drainage, unless incidental to surface drainage, has seldom been adopted in the construction of military airfields. Facilities and time are too short. Direct measures to improve subsoil or thicken base-course gain ready preference over indirect and speculative alternatives. Further, soil and water characteristics and disposition rarely justify its use. Only soils with a clay content less than 40 per cent., a volumetric change below 30 per cent. and a liquid limit under 40 per cent., can be effectively drained by sub-soil drains.

In certain regions or on some parts of existing airfields it may nevertheless prove the only satisfactory method of maintaining soil stability.

It may be necessary to deal with water percolating through a runway, inadequately sealed or of a gravel type; to intercept sub-surface water percolating from higher ground; to remove water liable to cause damage through frost action; or to lower the water-table of the field.

2. A full scheme of runway subsoil drainage would involve the laying most commonly, of a herring-bone system of concrete or earthenware pipes, butt-ended with  $\frac{1}{4}$ -inch open joint. The top half of the open joint should be covered with a clay "sausage" to prevent infiltration of silt. Pipes, of 6-inch minimum diameter, should be laid at depths of 3 to 4 feet, according to the permeability of the soil. Laterals, 35 to 75 feet apart, would discharge into side-drains, about 5 feet deep, at the runway or shoulder edges.

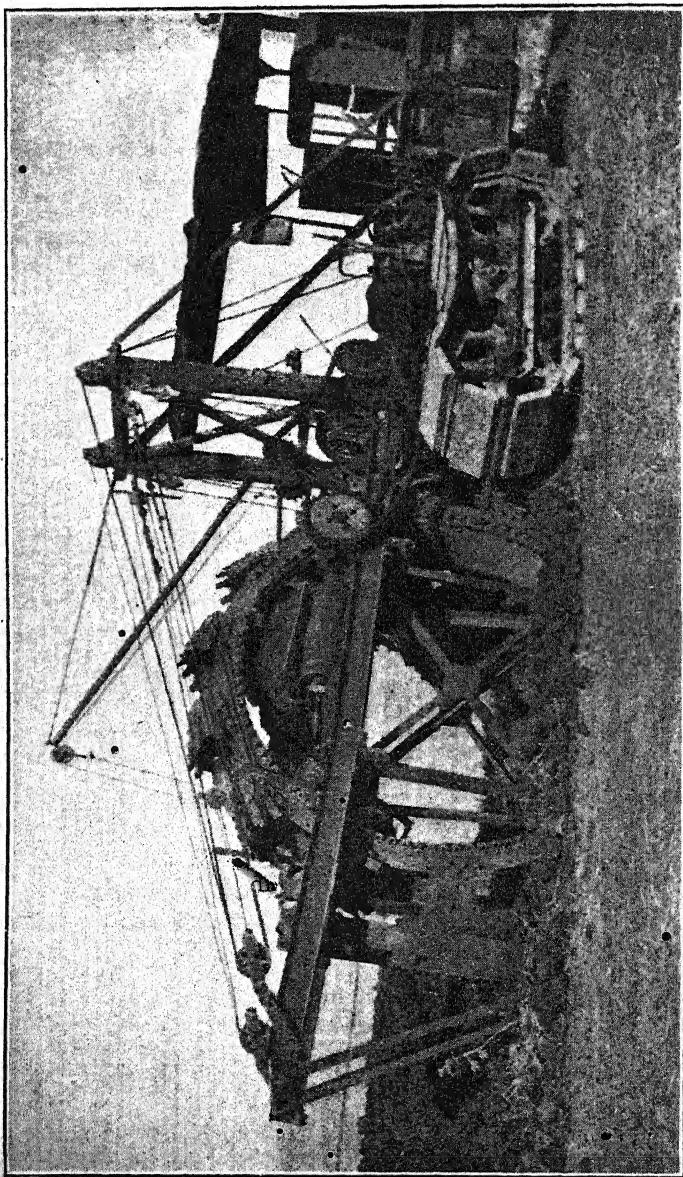


PLATE 13.—BUCKEYE TRENCHER IN COTTON SOIL. SYRIA

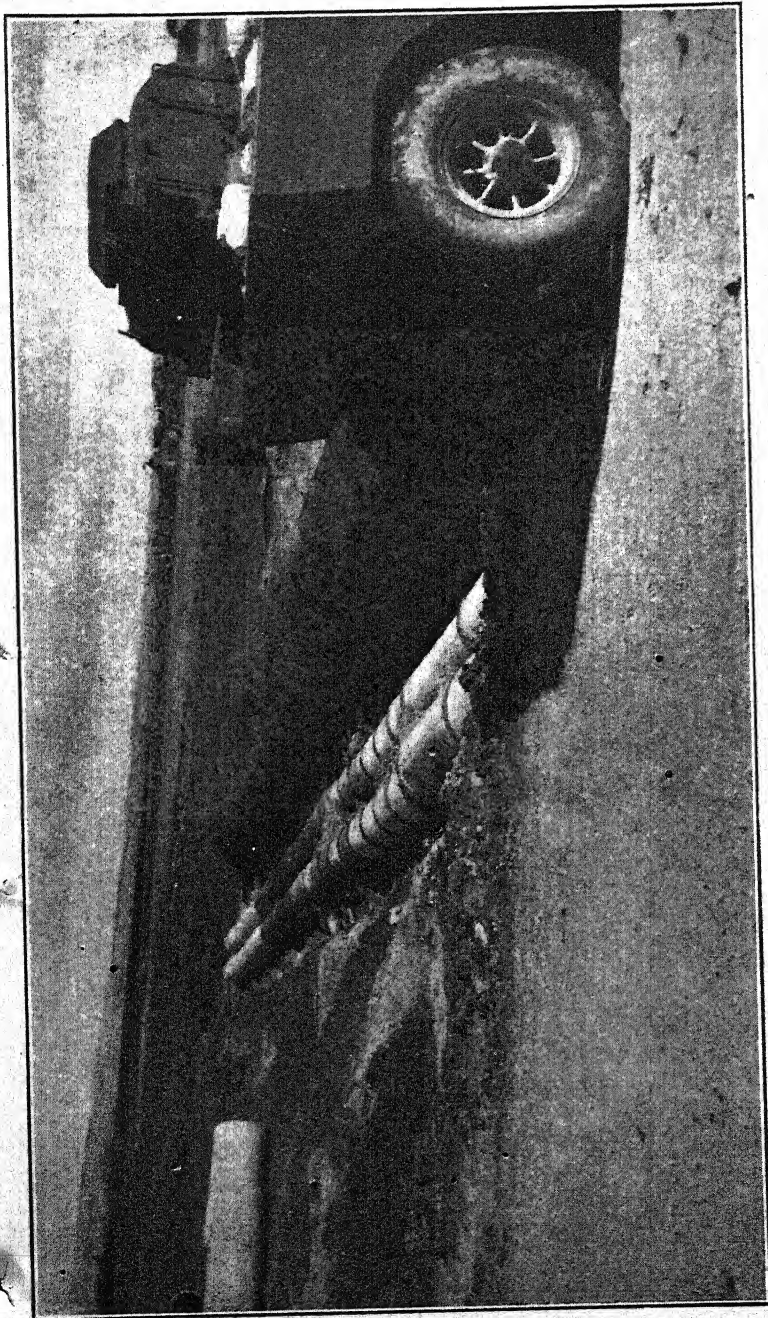


PLATE 14.—OPEN DRAINAGE ON BOMBER AIRFIELD WITH PIPING UNDER TAXI-TRACK. TUNISIA

These side drains may combine the function of collectors for runway run-off and the subsoil drains. They would then have porous fill throughout. If for subsoil water only, the top portion could be an impermeable back-fill.

Such subsoil drains below a runway, like the culverts discharging from one side of the runway to the other, must obviously be of the best standard of construction.

#### SECTION 52.—MOLE DRAINAGE

Mole drainage is essentially an English practice and has been rarely adopted abroad. The range of effective employment is narrow but, where soil texture and contours are suitable for its use, the mole plough can be a highly profitable piece of drainage equipment. The plough consists of a horizontal boring tool carried at the end of a vertical knife on a wheeled frame for attachment to a tractor. This makes a "tunnel" 3 inches in diameter, at a depth which can be varied between 1 foot and 2 feet. The knife leaves a narrow slit in a cohesive soil, down which water penetrates to the channel. Gravel can be made to trickle behind the earth blade to assist in maintaining the capacity of the system. Speed of channelling is very great. Results, always speculative, can never be harmful and will often do good.

A close compact clay soil gives the best results.

#### SECTION 53.—TYPES OF DRAIN NEAR RUNWAYS

1. Common types of drain to remove water from runways and strips are :—

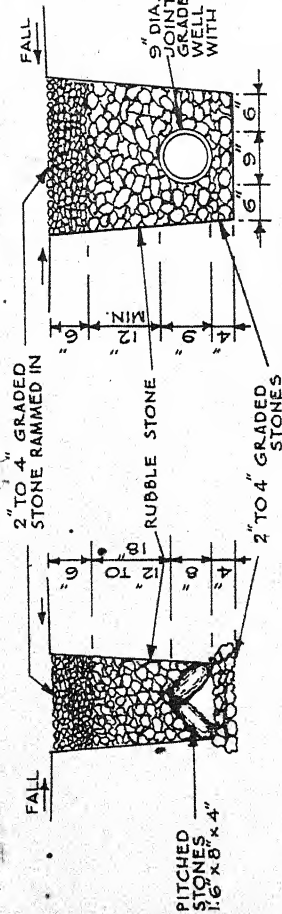
- (a) Open, shallow, and wide V-ditches, or saucer drains, along the outside of the shoulder or flight strips of emergency service.
- (b) Filled rubble or pipe sub-drains along the sides of runways, over which aircraft can run on to the shoulder or flight strip without mishap.

2. **Open ditches.**—These normally will be not less than 25 yards from the runway edge. They should be so flat as to minimize risk of serious accident if run over in dry weather. In wet weather, it is probable that the uncompacted cleared area beyond them would be impassable for taxi-ing and unfit for emergency landing. The ditches would not therefore appreciably increase the risks of accident to aircraft.

In North Africa, where open ditches have been common practice in the pre-winter programme, the ditch has a maximum depth of 2 feet gained in a transverse slope of  $2\frac{1}{2}$  per cent. on the 80 feet uncompacted graded strip outside the edge of the "shoulder".

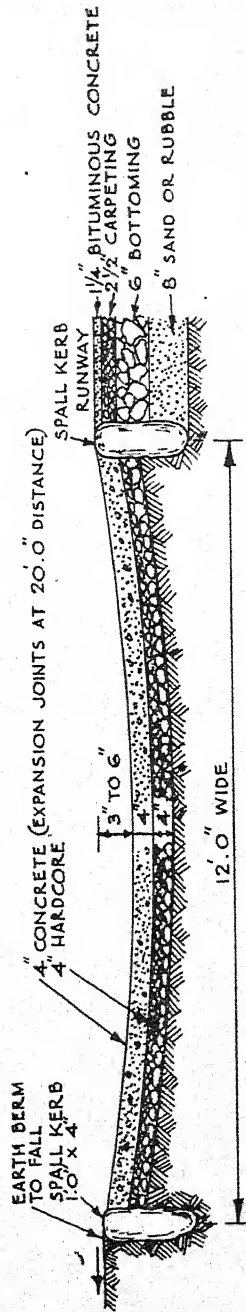
In India, the "Saucer" drain, an almost invisible valley drain, with a maximum depth of 3 inches in 100 feet, designed to give no danger on landing or taxi-ing is specially favoured. One such saucer would dispose of 4 inches of rain per day from a whole runway.

3. **Filled rubble or pipe drains.**—The degree of security is the measure of work and materials. The best form of runway side collector is the open jointed pipe, of 6-in. minimum diameter, in a stone-filled trench. This type is much less liable to lead to the formation of dangerous cavities than the plain rubble or stone-filled French drain, apart from the greater freedom from choking and loss of capacity. See Plate 15.



RUBBLE DRAIN (FRENCH DRAIN)

OPEN JOINTED PIPE DRAIN



CONCRETE CATCH GUTTER

PLATE 15.—TYPES OF AIRFIELD DRAINS

For pervious back-filling of drains, local stone supplies and engineering facilities will govern the specification, in the light of soil and contour characteristics. Crushed rock, slag, gravel, oyster shells, and many other hard durable materials, with a high percentage of voids, can be used. For graded stone, the best sizing is from 3 inches minimum to 6 inches maximum gauge.

The filling of the top 6 inches is particularly important. Preferably, this should be composed of well-graded 2-inch to 3-inch stone, consolidated with bitumen to avoid displacement. This capping must be strong, but pervious. Many soils demand the adoption of slab lining of drains to check the erosion of sides and the choking of porous fill. Improvisation and salvage, in operational areas, may provide adequate methods of making a secure drainage channel. Hollow tile bricks, empty oil drums, old tiles, slabs, and bricks are commonly used.

Trenches to carry piping should be 12 inches wider at the bottom than the pipe diameter. Pipes must be carefully laid upon a firm and porous foundation, true to grade.

#### SECTION 54.—METHODS OF CONSTRUCTION

1. Open ditches may be cut with a motor grader, angle dozer, scraper, power shovel or dragline, according to the cross section required. Narrow ditches for pipe or French drains are excavated by ditchers and by hand-labour. Work must be done closely to grade to obviate heavy trimming of humps or backfilling of depressions subsequently. Sometimes it will be necessary torevet the sides of the drain temporarily, until the piping, stone and back-fill are in place.

2. When natural impervious soil is back-filled, for sub-surface drainage, the material must be compacted in layers as thoroughly as in the filling of a runway bomb-crater, if liable to be crossed by aircraft. Gravel or stone used for porous fill must be well selected for its function, the coarsest grades going to the bottom. Good work in pipe-drain construction is best evinced by the true and stable bedding of the pipes upon a well-graded durable and porous foundation. In French drain construction, with heavy stone packing or open tiles for the main channel, the chief danger is cavitation, leading to weakness at the surface, and to choking, liable to cause complete local failure of the system.

#### SECTION 55.—OPEN VERSUS COVERED DRAINS

1. One of the most controversial questions associated with the drainage of operational airfields, as opposed to peace-time practice, concerns the relative merits and defects of open and covered drains. Demands for safety and economy may seriously conflict.

2. Consider the simple case of a paved and sealed runway on loamy soil, of a type liable to rapid loss of stability under rain. The apron on each side is of compacted base-course material, with a width of 75 feet.

3. If a French or pipe drain runs adjacent to the runway, the apron is subjected only to direct rainfall and will dry out rapidly. If there is no such interception, the run-off water flows over the apron, probably with detrimental effects which will greatly retard its return to service in emergency. Any channels cut by the flow could be readily repaired by maintenance parties, but time for infiltration and evaporation would be necessary to restore the surface stability.

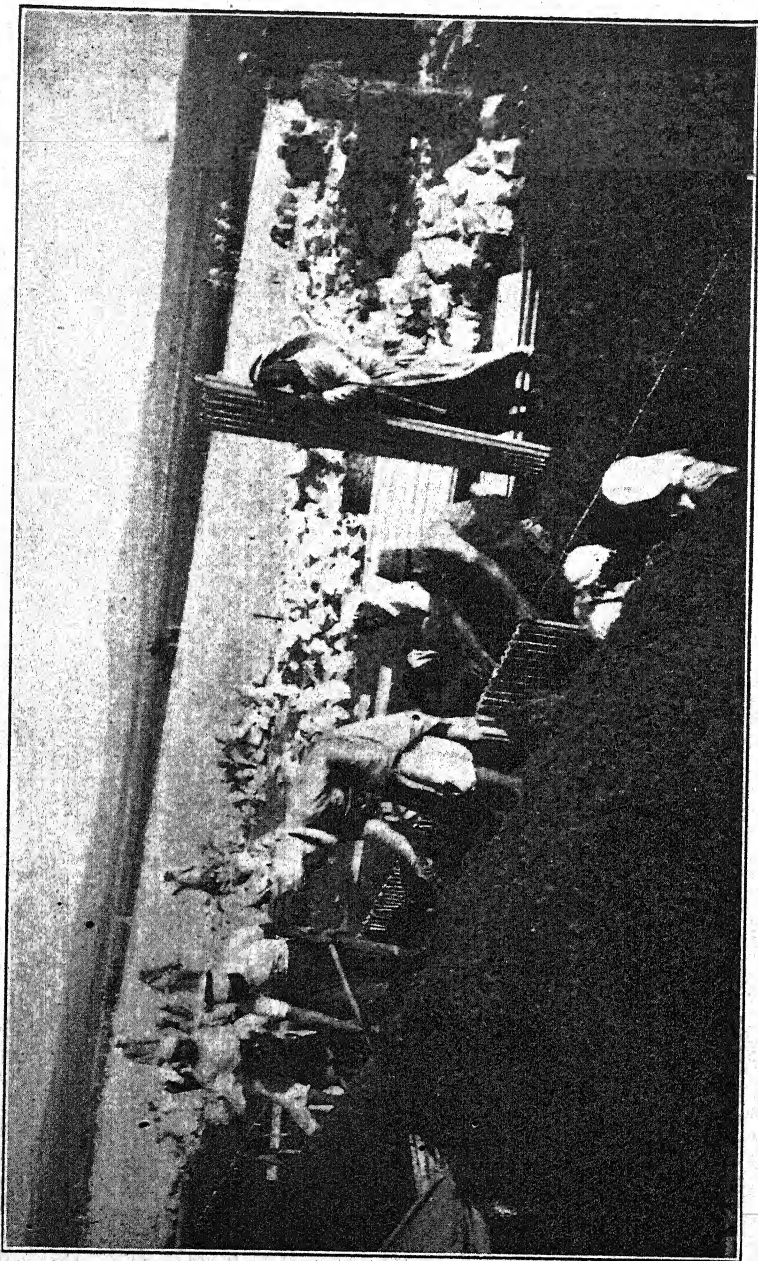


PLATE 16.—C.G.I. SHEETING TO CHECK INGRESS OF SUBSOIL WATER BELOW SOLED  
MACADAM RUNWAY

4. The safety of the sub-drain, with its porous capping designed to carry heavy loads, may be more apparent than real. The behaviour of the trench wall under the scouring action of flood water is doubtful without the test of time. On the other hand, the bad features of the open shallow ditch are obvious, the danger to aircraft, in certain circumstances, and the inevitably narrow width of the flight-strip, unless open-drains of the V-type are to be made unduly deep.

Such open drains are more dependent for their success upon favourable airfield contours than the French drain, because of more exacting depth restrictions, and it is more urgent for open drains to dry out quickly, to avoid dangerously boggy conditions.

5. Saucer drains are strongly advocated in India, in which country drainage problems are often particularly acute. Such drains are shown to be useful, cheap, and efficient for removing storm water. They are developed from gently sloping ditches of the least depth necessary for flow of water, by cutting their sides back at 1 in 200, giving a depth of only 3 inches per 100 feet of breadth. In this form they are invisible, and their beds comply with standard requirements for safe taxi-ing. A layer of gravelling material may be required to make their surfaces more rapidly safe for taxi-ing across. Their use is claimed to be nothing more than grading the ground systematically to comply with drainage and landing requirements. Contours upon an area suitable for runways are often satisfactory for these shallow drains, but soil and rainfall factors need close study to avoid the possible creation of a long-persisting bog.

6. The constructional advantages of open ditching are so substantial and the practical benefits so commonly attainable without undue risks, that its application, as widely as possible, should only be ruled out in favour of pipe or rubble drains for sound and urgent reasons.

7. In all circumstances, where surface security is dependent upon a big drainage scheme, the maintenance service must be efficient and alert.

#### SECTION 56.—CAPACITY OF CHANNELS, CULVERTS, AND PIPES

1. Formulæ used for estimating the capacity of pipes and channels are given in Appendix VIII.

2. Examples of practical conditions in India are given in the following results, based on a formula introducing constants for different types of drainwall. (Slope 1 in 1,000) :—

- (a) French drain, with two tiled channels of 7 inches by 5 inches. Flow 0.16 cusecs, apart from flow through back-fill.
- (b) 6-inch, well-laid, concrete pipe, for seepage. Flow 0.08 cusecs.
- (c) Masonry flume, 11 inches wide running 12 inches deep. Flow 1.18 cusecs.
- (d) Earth saucer drain, 3 inches deep and 100 feet wide. Flow 4.2 cusecs.

3. The low gradient of 1 : 1,000 would demand good workmanship. Where physical conditions allow, gradients of not less than 1 : 750 are recommended, at the cost of more frequent sub-drains or other diversionary channels. But no fixed rules can be laid down without detailed consideration of the layout and contours as a whole.

#### SECTION 57.—INCIDENCE OF FROST

1. The ill-effects of frost action are well known, especially in Western Europe, where the heaving of road and airfield surfaces by direct ice action, and the break-up of stable surfaces upon the thaw are common phenomena. The danger is most acute when the water-table is near the surface and when the soil is of a consistence or disposition conducive to the formation of ice layers.

2. Lowering of water-table may call for first consideration, for it is within the capillary fringe, reaching several feet above the water-table in finely textured soils, that the harmful ice deposits form.

3. Clean sand and gravel freezes homogeneously without the growth of ice layers, whilst irregular silty sands, silts, and silty clays constitute the most troublesome type, unless well drained.

4. Sub-soil drainage, below the depth of frost penetration, may be essential for security, combined with major schemes for dropping the water-table.

#### SECTION 58.—WATER-TABLE

1. Ground water investigations should determine the depth of the water table, below datum, at a sufficient number of points to allow the production of a water-level contour plan as a basis for drainage planning. The contours correspond, as a rule, with the configuration of the surface.

False water-tables may be expected in ground containing layers of impervious soil. Such conditions cause trouble unless the impervious catchment can be broken down readily by making outlets to a lower porous level.

2. Evidence of a rise to a level liable to weaken the sub-soil under paving may not be easy to obtain in the course of a soil survey. Whether the question is of importance or not will be clearly disclosed by local investigations.

Plant life may give guidance. If the water-table, on flat ground suitable for airfields, rises to within 2 or 3 feet of the surface, there will be an absence of cultivation.

3. In dealing with a high water-table below a prospective runway liable to weaken the sub-soil, the chances of stability can be improved by intensive sub-soil drainage, by a major drainage scheme affecting the whole area, or by providing an underlay and base course of a thickness calculated to spread the wheel-load adequately.

## SECTION 59.—CATCHMENT METHODS

1. Concrete catch gutters and inverted crown runways have both been in use upon all-weather airfields in operational areas abroad. Although unlikely to be further employed in war, the systems are based on instructive principles which throw light upon other expedients.

2. Concrete catch-gutters, along each side of the runway, have been constructed, 12 feet wide and 3 inches deep; 4 inches thickness of concrete on 4 inches consolidated underlay, in 20-foot bays. Water is discharged into main side drains at suitable intervals. These shallow drains can be designed for a safe run-over by aircraft, but the inflexibility of the layout, necessarily conforming closely to runway gradients, restricts the application severely. (See Plate 15.)

3. An all-weather runway with an inverted crown has the obvious advantage of dealing rapidly with the runway catchment through a single drain. The defects of this concave section are the necessity for catch-pit covers along the runway surface, the need for high efficiency in the sub-drain construction down the middle of the runway, and the chance of a considerable quantity of water along the centre trough during rains. There should be no muddy water flowing on to the runway from outside. The provision of an outward slope to berms and aprons is simplified by the profile across the strip, which will show a natural watershed along either edge of the runway "basin," if constructed on level ground.

4. Designs for catch-pits and junction boxes of flush type follow accepted civil practice for comparable demands. In airfield work, the prime consideration is strength of cover and seating, to minimize risks to aircraft taxi-ing or running over these numerous inlets. Covers are commonly made in reinforced concrete or selected dense timber, free from knots, in place of cast iron or steel grates. Many minor accidents have followed bad workmanship or failure to provide a big safety factor in design.

## SECTION 60.—AIRFIELD SPECIFICATIONS

1. Specifications commonly given in England :—

- (a) French drains; porous concrete pipes; open joints; filled with 2 to 3 inches hard core, lightly consolidated to within 6 inches of surface, along tracks, and 4 inches along runways.
- (b) Aprons, between concrete runways and drains, in tar macadam, 2-2½ inches thick.
- (c) Drain pipes. Glazed ware or concrete.
- (d) Soakaways.—Walls 9 inches thick, honeycomb brickwork, corbelled over on two sides and set on 9-inches concrete foundations, 1 foot 9 inches wide. Cover door with 4-inch pre-cast reinforced concrete slabs.
- (e) Manholes.—Foundation slabs 4 inches thick, if under 6 feet 6 inches deep, and 6 inches thick for greater depth.
- (f) Walls, 9 inches thick.

2. Construction of covers liable to be accidentally run-over by aircraft, calls for the closest inspection.

## CHAPTER 7

## BEARING CAPACITY

## SECTION 61.—GENERAL

1. Reliable methods have been developed in the U.S.A. for determining the bearing capacity of soils in the field. A large and rigid circular plate approximating to the size of the area of contact of an aircraft tyre is placed on a carefully prepared base, and the load required to produce a 0.05-inch deflection determined. The "Modulus of Sub-grade Reaction," which is the stress required to produce 1-inch deformation, is calculated by proportion. This procedure is based on the fact that over this small range of deflection the soil behaves very nearly elastically. From a knowledge of the sub-grade reaction, the necessary thickness of pavement can be determined from design curves.

2. An apparatus has been recently developed in England for the rapid determination in the field of the shear strength of clay by means of unconfined compression tests. From the results obtained, the thickness of pavement required to reduce the stress in the sub-grade soil below a safe value can be calculated or read from curves. The range of soils, to which this test is applicable, is limited.

3. The empirical method adopted by the California Division of Highways employs a test termed the "Bearing Ratio" and has been extended by American Engineers for use in the design of airfield pavements (for which purpose some modifications of the original test procedure have been necessary). Details of this practice are given in Appendix VI.

4. All such tests should be made at a density comparable to that obtained in construction, which involves special difficulties in regions of marked seasonal variation.

## SECTION 62.—LIMITATIONS OF PRECISE METHODS

Such precise methods are applicable only to the finer estimates required for heavy and permanent construction. After an accurate estimation of the thickness of pavement to spread the load, highly speculative factors still remain for determination, which lead to the adoption of some arbitrary factor of safety, reducing the practical value of precision in any basic calculation. These unknowns include the fall in quality of sub-grade with ingress of water, the intensity of traffic, and the landing impact forces, apart from the ruling uncertainty of ultimate wheel-loading for which provision should be made.

## SECTION 63.—OPERATIONAL RISKS

1. Under operational conditions, risks will be taken in order to attain maximum speed of work and economy of resources, at the cost of heavier maintenance. Thick pavements and base courses are rarely practicable. The stabilization of the natural soil and the retention of its bearing strength become the primary aims. Thin pavement courses, involving minimum tonnage and transport requirements, are adopted wherever practicable. These may be of high flexible type, waterproofing and thus maintaining the natural strength of the soil; or of semi-rigid type, such as pierced steel plank, giving a fairly durable wearing surface and distributing loads in some useful degree.

2. Nevertheless it is the duty of engineers to make thorough field observations to throw light on bearing capacity, in support of any laboratory determinations. The additional information obtained will be the more significant wherever conditions appear to be in the balance, and where evidence gives warning of serious deterioration after rain or with rising water table.

#### SECTION 64.—PRINCIPLES

1. The unit pressure on the surface approximately equals the aircraft tyre pressure. The unit pressure on sub-grade is less than this because the load is spread over a greater area, dependent upon the thickness of the courses laid. Thickness is increased until the wheel load is delivered to a weak sub-grade at a safe unit pressure.

2. Except for rigid pavements, the distribution of load depends mainly on inter-particle friction. The effectiveness of this distribution varies widely with the shape of the particle, and the degree of compaction or intimacy of the contact between the bearing surfaces. A rough working assumption, for a non-rigid pavement, is that the effective loaded area is increased by the projection outwards of the tyre contact area, in bell-like fashion, at an angle of about 45 degrees through the pavement. Thus, a load bearing upon 6 square feet at the surface is carried, below a 6-inch pavement, by 12 square feet at the sub-grade.

3. It can be established that settlement under the same unit load varies roughly as the square root of the loaded area, with allowance for differences of cohesion in various soils and materials. Alternatively expressed, the strength of pavement or base required varies roughly as the square root of the wheel-load, *e.g.*, for certain fighters and bombers as 120 : 180.

#### SECTION 65.—FIELD TESTS

1. In field tests of bearing capacity, it is desirable to reproduce, as closely as possible, the load and bearing surface represented by the type of aircraft in view. Without special mechanical apparatus, a heavily loaded lorry, low-loader or transporter, with highly inflated tyres, is the most practical means of obtaining contributory evidence.

2. Other methods of field-test include the use of a strong three-legged table or stool, of a size and with leg cross sections to suit expectable results. Upon gradual loading until failure of ground support is observed, valuable guidance can often be obtained and, for certain types of cohesive soil, a fair measure of accuracy.

3. Officers concerned with airfield design can develop their soil sense and ability to judge bearing strength by repeated use of a strong staff, tipped with a cone-shaped metal prod of about 2 square inches in cross-section. By applying 70 per cent. of his weight in a downward thrust, a man will be able to apply a pressure of about 60 lb. per square inch. A similar staff of 3 square inches, with a cross-bar allowing two men to impose their weight, a pressure of 70 to 80 lb. per square inch can be developed.

4. The interpretation of results is based on experience gained by "matching" tests, on a range of comparable soils of known composition and engineering characteristics.

## CHAPTER 8

## SOIL STABILIZATION

## SECTION 66.—GENERAL

1. Stabilization is a wide term covering any method of developing and maintaining the capacity of a soil to resist distortion under wheel-load, or displacement under the tractive or braking effort applied to a wheel. In airfield construction, stabilization methods are applied to :—

- (a) A natural surface to create a durable landing area with or without the addition of a prefabricated mat ;
- (b) a base course, below steel planking or any type of surface pavement ;
- (c) a surface course.

2. The common methods of stabilization applied to airfield work may be classified as mechanical, bituminous, cementing, or miscellaneous (including experimental chemical agencies).

Particulars of work done in airfield practice are given under the head of Specifications in Chapters 13, 14, and 15.

3. The use of portable steel mats and waterproof carpets is a form of stabilization in its widest sense.

## SECTION 67.—FACTORS INFLUENCING METHODS OF STABILIZATION

For all soils and aggregates, methods of stabilization are related to the following factors :—

- (a) *Grain-size distribution or grading.* The closer a soil or aggregate approaches the ideal smooth grading curve of proportional grain-sizes, *i.e.*, the better the "grading," the less the voids and the denser the mixture. Soil stabilization involves the mixture of complementary materials with the natural soil, in order to increase the efficiency of compaction.
- (b) *Particle shape.* The more angular the fragments, the greater the natural internal friction between particles. Angular crushed rock, when consolidated by rolling, has high internal friction and becomes relatively stable. Inversely, rounded particles are unstable, as clearly demonstrated by the behaviour of wind-blown sand of equal sizing in the sand-bitumen mix process, with the addition of finer grades.
- (c) *Compaction.* This is applied, most effectively at a controlled moisture content, to develop internal friction and cohesion. Compaction aids run-off and evaporation. At maximum density, the soil does not readily absorb more moisture.
- (d) *Restraint or "boxing."* The stability of any load-carrying layer is affected by the degree of restraint to distortion by adjacent soil, as evidenced by the behaviour of non-cohesive soil under metal track, with a carpet of coir matting, heather, palm leaves, etc., or under bitumenized hessian.
- (e) *Binder effect.* The inherent stability of soil or aggregate mixtures is increased by the additional binder effect of cement, bitumen, or other agents,

1. The most common and important method of stabilization is mechanical compaction. The fundamental principles must be understood thoroughly by all engineers responsible for reconnaissance, construction, or maintenance.

Application of correct methods will reduce tonnage demands to a minimum or improve the prospects of effective service. Sound knowledge is also necessary to avoid needless work. Time has occasionally been wasted upon scarifying, watering and rolling a natural surface of more than adequate strength for the services required in its natural state.

2. The following analysis of the main factors of soil compaction is based upon reports by the Road Research Laboratory :—

- (a) The bulk density of the solid particles in the soil, commonly termed the "dry density," is a measure of the closeness of packing of the soil particles and hence of the state of compaction of the soil.
- (b) This density can be measured in the field, and compared with the results of laboratory tests, in which a standard amount of compaction is applied.
- (c) In general, compaction expels only air from the soil.
- (d) With soil of given moisture content, density increases with the amount of compaction at a decreasing rate until compaction becomes difficult and a limit is reached. This occurs where only about 3 to 4 per cent. of air is left in the soil.
- (e) With soils of varying moisture content, to which equal amounts of compaction are applied, a certain moisture content exists at which a maximum dry density is obtained. This moisture content is termed the "Optimum Moisture Content."
- (f) Both maximum density and optimum moisture content vary with the type of soil and amount of compaction applied.
- (g) Extra rolling only benefits soils rolled at relatively dry consistence at moisture contents below the optimum.
- (h) In general an increase in the compacted density increases the strength and stability and reduces liability to settlement. The capacity to absorb water decreases with an increase in the dry density.
- (i) In general, the effectiveness of all compaction equipment decreases with increasing depth of soil ; hence the importance of compacting soil in thin layers.
- (j) Compaction equipment is of three classes :—
  - (i) Rollers : Smooth steel-wheeled rollers  
Pneumatic-tyred rollers (wobbly-wheeled)  
Lorries and other vehicles  
Track-laying tractors  
Sheepsfoot rollers
  - (ii) Rammers : Gravity  
Internal combustion  
Pneumatic
  - (iii) Vibrators.
- (k) Of these various types of compaction equipment, ramming is effective on both cohesive and non-cohesive soils. Rollers are effective mainly on cohesive soils, and not on loose cohesionless soils. Vibrators are effective on cohesionless soils, such as loose sand, but are not effective on cohesive soils.
- (l) The admixture of stone, up to about 50 per cent., has little effect on the moisture-density relationship of the soil mortar, the aggregate acting mainly as a displacer.

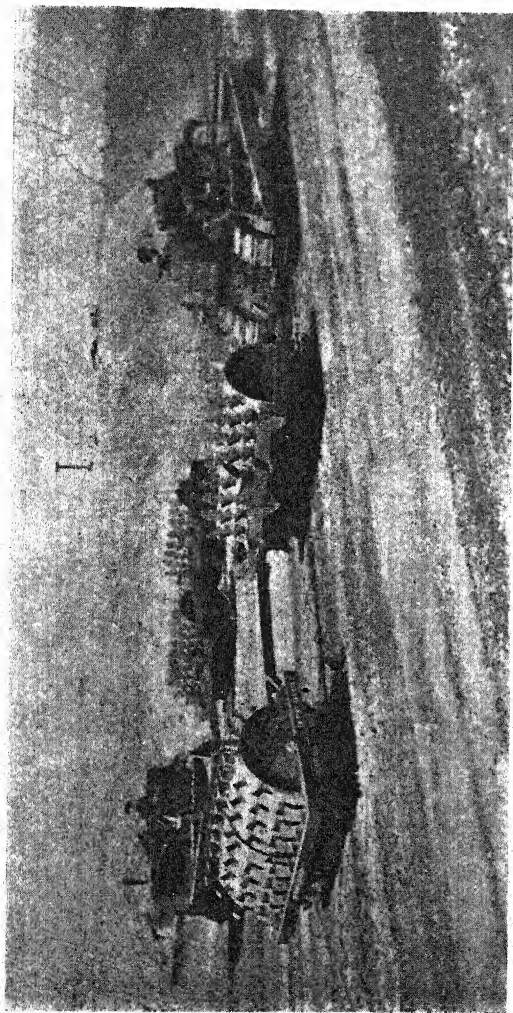


PLATE 17.—SHEEPSFOOT ROLLERS—TOWED—TWO DRUMS IN LINE,  
COMPACTING SUBGRADE

### SECTION 69.—PRACTICAL STANDARDS

1. A soil compacted to maximum density has a substantially lower absorptive capacity for water and its stability is little affected by evaporation, unless a non-cohesive type.

2. A standard of 95 per cent. maximum density or 95 per cent. compaction (U.S.A.) is commonly specified for work, with sheepfoot rollers, on base courses and runway shoulders, and 90 per cent. for fills in the foundation.

3. For determining the compacted density attained in the field, a cylinder of compacted soil is removed from the formation and weighed against the measured volume of the hole, for comparison with laboratory standards.

For guidance, a few standards of maximum density are :—

Type	Weight lb. per cu. ft.
Heavy clay	90—100
Sandy clay	114
Sandy soil	120
Gravelly soil	120—130

4. Optimum moisture can be roughly tested in the field by cupping a sample of the soil between the hands. If it forms a compact ball and holds together, the soil is near optimum. If, when the sample is squeezed, water exudes or the ball takes a shiny appearance, it is too wet. If the ball breaks apart easily, it is too dry.

### SECTION 70.—BLENDING SOILS

1. In order to obtain a well-graded soil capable of effective compaction, it may be necessary to blend the surface deposit with other material from borrow pits or neighbouring sources.

2. Proportions to be used in preparing trial mixes are guided by comparing characteristics of the individual materials. For sands and gravels, a gradation curve resulting from various proportions is first calculated. For a mixture of sand and clay, an indication of desirable proportions may be obtained in the Mobile Laboratory from the plasticity indices of the two soils.

3. With experience, the general type of complementary soil required for improving the existing surface can be judged roughly by observation pending laboratory guidance. The "feel" of a mixture of clay and sand soils will often indicate to experienced engineers whether the necessary grittiness has been acquired to allow friction to develop between particles.

#### 4. Example of soil stabilization—South-west Pacific area

(a) *Clearing vegetation and top soil.*—Kunai grass was cut by hay mower or burnt. Cut debris, and top layer of roots, and humus were then ploughed into windrows by a motor grader and pushed back by bulldozers. The remaining top soil (loam) was then cleared by scrapers and bulldozers and placed in stock piles beside the strip.

(b) *Formation.*—The naturally level site required very little grading. The porous subsoil required no drainage except where silt pockets occurred. These had to be cut out and back-filled with sand from surplus soil or borrow pits. Formation was then graded by motor-grader.

- (c) *Base course*.—Consisted of stabilized ridge sand (70 per cent. to 85 per cent.) obtained from local borrow pits, and top soil loam (30 per cent. to 15 per cent.) laid in three 5-inch layers, each mixed *in situ* and consolidated separately. Sand was spread by tipping lorries, in a layer about 4 inches thick, and sufficient top soil loam, taken from stock piles, was spread on top of the sand by bulldozer. The composite layer was then mixed and consolidated by disc harrow, rotary tiller, sheep-foot roller, pneumatic roller and motor-grader working in a gang in that order. Water was added if necessary. This process was repeated three times and resulted in a stabilized base course about 12 inches thick.
- (d) A seal or priming coat of No. 1 Tar was sprayed on hot.
- (e) A wearing course of river gravel was then laid in two layers. The first layer, material passing the  $\frac{3}{8}$ -inch mesh, was laid at 1 cubic yard per 60 square yards; the second, material passing the  $\frac{3}{8}$ -inch mesh, at the rate of 1 cubic yard per 120 square yards. After each layer was spread it was sprayed with hot bitumen at the rate of 0.3 gallons per square yard and rolled. The surface was finally dusted with grit and rolled.

## CHAPTER 9

### AIRFIELD CONSTRUCTION METHODS

#### SECTION 71.—GENERAL

1. In any theatre of war subject to unfavourable weather conditions, methods of construction are governed more by soil characteristics, climate, and technical resources than by type of aircraft served. There may be little difference between the engineering requirements of a forward airfield, constructed on soil of low bearing capacity, and of a bomber or air-transport station on the L. of C. or near the Base.

Exacting demands imposed by heavy wheel-loading upon bomber airfields are often balanced by better geographical opportunities for the selection of sites with stronger sub-grade. The comparatively small requirements for advanced landing grounds may eventually involve a heavy engineering task, because of unfavourable soil, difficult drainage, and the great seriousness of any spell of unserviceability, however short.

Urgent fighter landing strips at Foggia were constructed approximately to the same specification as the all-service runways at Maison Blanche, which was the busiest airport in Africa. Heavier specifications were adopted in the construction of typical fighter runways in Palestine than of bomber airfields in England.

2. *Advance provision*.—Methods of construction can be grouped effectively by the different products constituting the principal agents for binding, stabilizing or covering the wearing surfaces. Supplies demand provision by long-term planning and their selection influences the training of the engineer troops responsible for construction in the field.

Mechanical equipment required for clearing, grading, compacting and stabilization of sub-grade, and for the drainage of airfields, represents a supply of comparatively small variation. All main types of plant will nearly always be needed, varying in ratio only, in accordance with regional differences of soil, contour and vegetation.

In general, principles and practice conform closely to those of road construction, thus simplifying demands in war for supply, maintenance and pooling of essential equipment and for the training of operators in the field. On the other hand, the surfacing of airfields is a more variable task, which introduces a number of new problems peculiar to aircraft needs.

**3. Trend of policy.**—In spite of constant increases in weight of aircraft, the trend in recent engineering practice, for military airfields, has been in the direction of lighter and more flexible pavements for short or medium term use. The tendency has been to help the sub-grade to carry the full unit load, while the superimposed material maintains the strength and quality of the sub-grade, and provides a wearing surface of suitable texture.

War restrictions in plant and transport have played a part in the growth of this doctrine. Less materials and machinery will generally be used in raising the bearing capacity of a soil than in providing thickness or strength of pavement to reduce the unit load imposed upon it.

Technical progress has been largely induced by the growth of aviation.

Equipment for earth-moving and compaction, produced on an unparalleled scale, has been improved in efficiency and scope, and many advances in technique are resulting from a better co-ordination of practical experience and scientific research.

**4. Formation work.**—The bulk of the preparatory earthwork done upon a new airfield site is of the same type, in a given locality, for all methods of surface construction. A level surface of the highest economic strength, with thorough drainage, will be required whether the area is to form a natural landing ground or is to be covered with a portable mat or a heavy pavement.

For details of technical work on formation, reference should be made to Military Engineering, Volume V, Part I, Roads. Only a few outstanding features are outlined below:—

**5. Grubbing and clearing.** The need for clearing timber and other heavy vegetation is rare in Europe, compared with Southern Asia and other tropical countries. The clay or loamy soils characteristic of favourable flats in Western Europe are commonly reserved for pasture or the cultivation of crops. Small work on hedges, shrubs and other light vegetation, and on boulders is common. Light vegetation may be cleared by hand, by rooter or angle-dozer of appropriate capacity.

Heavy grass is cut by tractor or Jeep-drawn mowers. If practicable, it should be left about 6 inches high by setting the mower-blade as high as possible. Burning of grass, though sometimes practised, is liable to leave much ash, and render the soil more friable and dusty. The easiest way to clear small trees, growing densely, is usually to sling a 1-inch diameter wire rope between two bulldozers and drag the rope over the area to be cleared. Power saws are efficient for medium stems.

All heavy roots, stumps, etc., should be grubbed out to a depth of 12 inches below the natural or the finished surface level. Grub-holes must be carefully filled in, layer by layer, to allow thorough compaction.

In the Pacific Islands the clearance of vegetable debris and humus is a heavy preparatory task. Where the undergrowth and creepers are very dense, the ground is usually too swampy for runways, but it may still have to be cleared for approaches and taxi-tracks.

Large trees are felled by cutting or explosives. If trees are to be subsequently grubbed, height of stumps should be 2 to 3 feet. Grubbing and clearing can generally be started before layout is fixed in detail. Plant should be sent forward early.

**6. Frequency of tasks.**—In order of importance airfield work comprises predominantly :—

- (a) *Grading to levels*, with motor grader and less frequently with tractor-drawn grader. The motor grader is the airfield engineer's most valuable item of war equipment, because of its capacity, adaptability and mobility.
- (b) *Rolling*, with Diesel smooth steel, two-wheel tandem or three-wheel road-type rollers; also with multiple-wheel rubber-tired rollers.
- (c) *Scraping*, with carry-all type scrapers suitable for the medium hauls typical of airfield work. Roll-over scoops are little used.
- (d) *Scarifying, and compacting* with sheepfoot rollers, for a stabilized sub-grade.

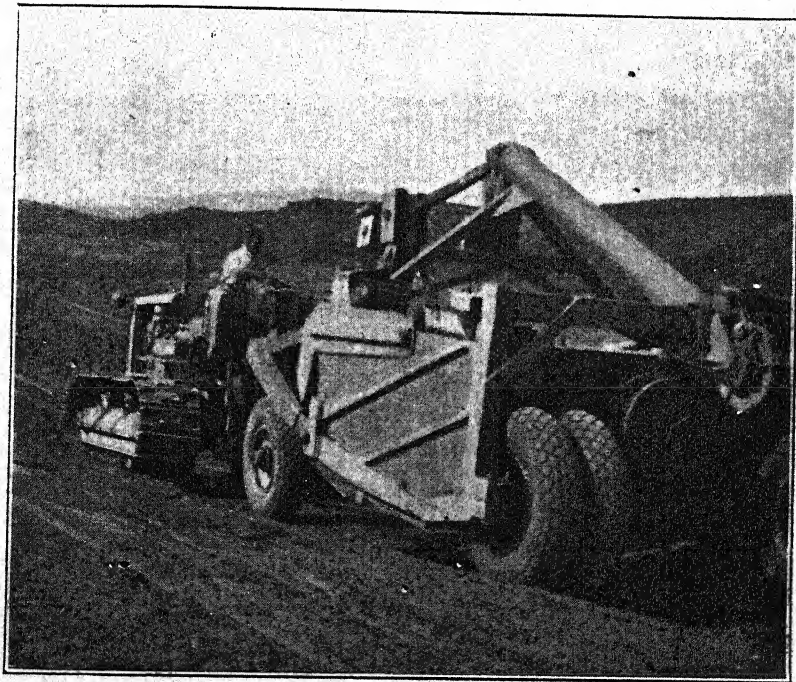


PLATE 18.—SCRAPER ON DESERT AIRFIELD

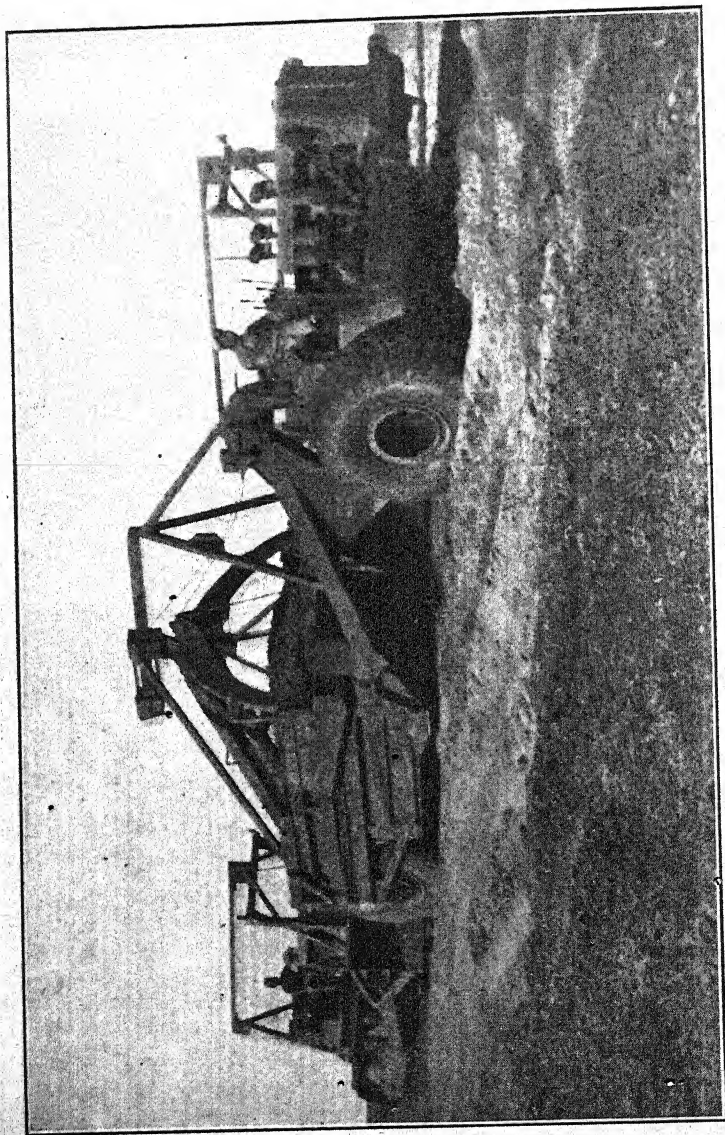


PLATE 19.—TOURNAPULL-DRAWN SCRAPER, WITH BULLDOZER PUSHING IN REAR,  
ON HEAVY SAND BASE-COURSE FOR P.S.P. BONE AIRFIELD, ALGERIA

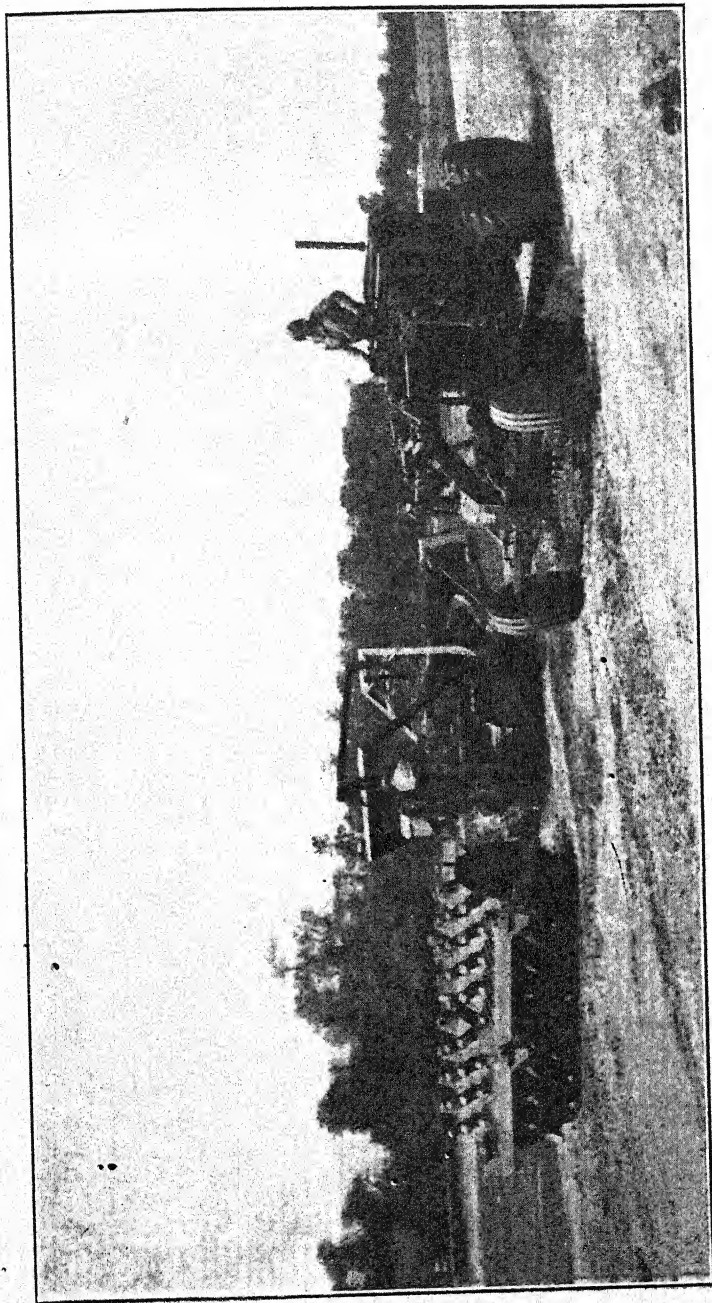


PLATE 20.—MOTORGRADER AND SHEEPSFOOT ROLLER—PREPARING LANDING GROUND

The sub-grade is brought to required lines and grades after earthwork is roughly completed.

If there is time and need for heavy improvement of sub-grade, to serve the subsequent coverage decided upon, the entire area is scarified, to a depth of about 9 inches. It is then moistened to approximately optimum moisture content, by sprinkling, and compacted with a sheepsfoot or pneumatic tyred roller to nearly maximum density. All soft and yielding material which does not compact readily under rolling is removed and replaced with select material and compacted. The sub-grade is then fine-graded, using motor grader, and finally compacted with flat-wheeled rollers.

**7. Plant available in operational areas.**—Forming and grading plant carried by the two Road Construction Companies of an Airfield Construction Group in the European theatre of operations, 1944-5, included :—

Tractors, Class IV Angle-dozer and P.C.U.	...	...	...	4
Tractors, Class II Angle-dozer and P.C.U.	...	...	...	12
Scrapers, 8-yard	...	...	...	8
Motor graders	...	...	...	4
Graders, blade, tractor-drawn	...	...	...	4
Rollers, 6-ton	...	...	...	8
Rollers, sheepsfoot	...	...	...	6
Excavators, 10R.B. $\frac{3}{4}$ -yard (with miscellaneous attachments)	...	...	...	8

The small number of motor graders was governed by the limitations of supply.

For drainage, the equipment included : Ditchers, plough-type—4 ; Mole-ploughs—4 ; Trencher attachments to 10R.B. excavators—4.

## SECTION 72.—FACTORS INFLUENCING BASE AND SURFACE COURSE CONSTRUCTION

**1. General.**—Before the war few English airfields were constructed in concrete or macadam. Nearly all were turfed and given a maximum all-weather efficiency by good drainage and cultivation.

To-day, as a result of war activity in regions of contrasting physical and climatic conditions, the methods of airfield surfacing in use present a very wide and diversified range of engineering practice.

Combination of methods, as with the laying of pierced steel planking on a hard-core base or of square mesh track upon bitumenized hessian, still further multiply the possibilities of selection.

**2. Operational factors.**—The first considerations in choice of method of construction are the related factors of time and tonnage. The time allowed may range from :—

- (a) two to four days for an urgent fighter strip, needing the most skilful exploitation of natural surface conditions, with or without the use of some form of light prefabricated mat.
- (b) Two or three months for a bomber airfield, of semi-permanent construction.

For 1,000 yards of runway, 50 yards wide, the quantity of imported or locally transported materials may vary from 200 to 20,000 tons.

In all cases, engineer planning will have been necessary, long in advance, to ensure provision of special materials and equipment in adequate quantities. For "hasty" construction, the type of mat suitable for the soil and climatic conditions expected will have been

specified. For deliberate work, provision will have been made upon an assumption of the suitability of different methods involving the use of bitumen or cement. Pierced steel planking will appear as an intermediate expedient, suitable for less "hasty" A.L.Gs. or for less "permanent" airfields for bombers.

Broadly, therefore, the methods of work are governed by types of plant and imported materials provided on general assumptions—as a rule under severe tonnage restrictions—and by the adaptation of these resources to local conditions and materials, so as to provide the minimum acceptable facilities in the shortest time possible.

The distinctive features of war-time construction are that an extravagant use of any resources readily available may often be the best practice, that planning on liberal lines will often be necessary without detailed knowledge of task conditions, and that a standard of construction involving ultimate demands for heavy maintenance will often be the most appropriate, if aircraft safety is not to be unduly impaired.

**3. Types of course.**—The normal sub-division of runway components into sub-grade, base course, and surface or wearing course is commonly inapplicable to war conditions. The sub-grade will often be raised to a serviceable standard by the processing, or by the addition of a prefabricated mat contributing little to the distribution of the load. A typical cross-section of an airfield runway is shown in Plate 21.

Under favourable weather conditions, and when speed of completion is of primary importance, nearly all types of base course can be made fit for temporary service, without an additional surface course. Alternatively, a single course of suitable texture (e.g., sand-bitumen mix) can be readily made to fulfil both functions.

Normally, the surface course is a "quality" and the base course a "quantity" task, wherever their functions can be clearly defined.

### SECTION 73.—BASE COURSES

1. Excluding prefabricated mats, specifications for the surface course give less scope for variation than for the base course, in the construction of which a wide range of choice is often presented.

2. Materials are necessarily drawn from sources near or on the site. Gravels, sands and crushed rock are most commonly used. Inferior materials, suitable for methods of stabilization, may also call for consideration.

3. A substantial base course is required when the sub-grade does not provide sufficient support for the loads to be carried. Bases serve also to stifle mud in the sub-grade, liable to work through and weaken the wearing course or to make the landing surface slippery.

4. Nearly all sub-grades, even in desert areas, gradually accumulate moisture and get soft after they have been covered with an impervious base course—the degree depending on the soil, climate and effectiveness of drainage. Softening is furthered by impact and by vibration of moving wheel-loads in certain parts of the airfield. The combined thickness of base and surface courses is designed to provide the necessary load distribution for the sub-grade in a saturated condition, unless the runway is only for temporary service during favourable weather.

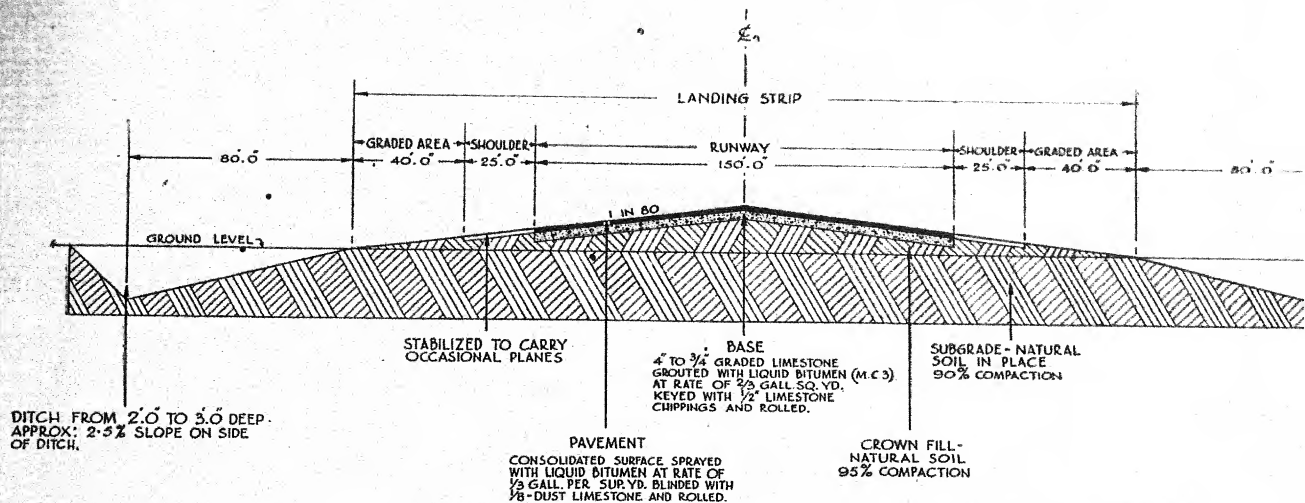


PLATE 21.—TYPICAL CROSS-SECTION OF LANDING STRIP—NORTH AFRICA

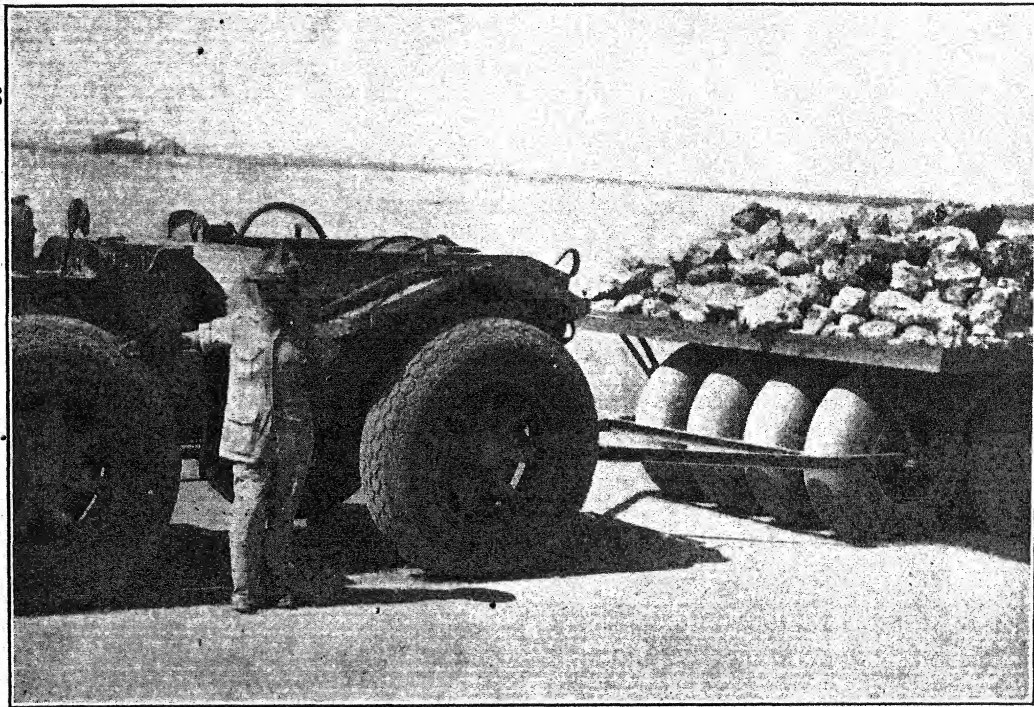


PLATE 22.—IMPROVISED RUBBER-TYRED ROLLER, USING OLD AIRCRAFT  
WHEELS

5. **Classification of bases.**—Methods of construction commonly adopted for base and surface courses will be described in Chapters 13 to 16, giving practical examples of work done upon a wide range of airfields in different countries. An accepted classification of base course types is as follows :—

(a) *Selected borrow material.*—Used as found, with little processing and compacted in layers 3 to 6 inches thick.

(b) *Stabilized soil base and stabilized sub-grade.*—A mixture of materials of controlled grading and moisture content. Mixed in place or by central mixing plant, 3-inch to 6-inch layers.

A wide range of materials would serve the above two types—such as gravel, sands, coral, shale debris, disintegrated granite or clinker. The dimensions of any particle should not exceed two-thirds of the thickness of the layer in which it is placed.

After compaction and final shaping, a prime coat of bituminous material is applied, as soon as possible, by pressure distributor at the rate of  $\frac{1}{4}$  to  $\frac{1}{2}$  gallon per square yard.

(c) *Gravel; crushed rock.*—This is another form of stabilization, depending more on the particle size gradation of screened or crushed and screened rocks and pebbles, without necessity for such close moisture control as in (a) and (b).

Built, to any thickness, in layers of 3 to 6 inches. The addition of a sand filler may be necessary to correct deficiencies in gradation. Rock particles must be of hard and durable composition. For material all passing 2-inch sieve, grading should conform roughly to :—

Passing 1-inch sieve	...	...	...	55–90 per cent.
Passing No. 4 sieve ( $\frac{3}{8}$ -inch)	...	...	...	25–55 per cent.
Passing No. 200 sieve	...	...	...	0–12 per cent.

(The fraction passing No. 200 sieve must not exceed 65 per cent. of the fraction passing No. 40 sieve.)

(d) *Cement stabilized base.*—Natural sandy or friable soil stabilized with cement; best suited to sites where suitable soil lies on the surface, as in coastal and desert areas, with adequate water available.

Soil must be free of clay balls and organic matter.

Cement is used at the rate of 7 lb. to 10 lb. and water at  $1\frac{1}{2}$  gallons per square yard per inch of compacted thickness.

A typical thickness is 6 inches.

Close control of all work, under laboratory instructions, is essential.

(e) *Lean-mix rolled concrete.*—In heavy construction, use can be made of lean-mix rolled concrete, which is intermediate in character between soil-cement and ordinary concrete. It is usually mixed in place and compacted with smooth-wheeled rollers. To enable the material to be rolled, it is essential to work with low water/cement ratios. With cement contents of 10–15 per cent. relatively high strengths are attained.

(f) *Bituminous stabilized base.*—Constructed by mix-in-place or plant mixers, where suitable sandy soil is available on site or easily imported.

Consolidated thickness 3 to 6 inches, commonly 4 inches; bitumen or tar about 1.5 gallons per square yard for 4-inch thickness.

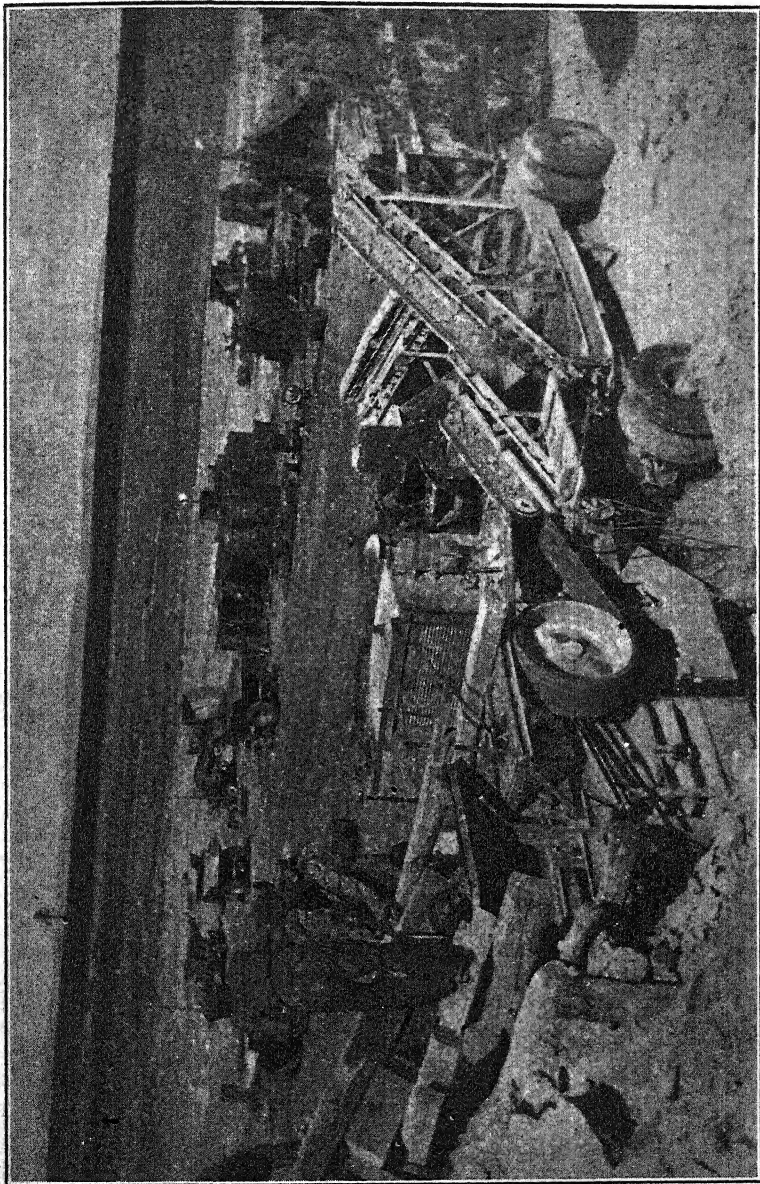


PLATE 23.—MOBILE CRUSHING AND SCREENING PLANT (R.E. QUARRYING COY.), TUNISIA

- (g) *Macadam base*.—Dry, waterbound or bituminous grouting.

This is a high quality base, built of angular crushed stone or crushed slag in layers 3 to 5 inches thick. A base of this construction, to meet heavy static requirements, would represent a surface course under operational conditions, with the addition of a suitable seal coat.

With dry-bound macadam, if the stone is hard enough to permit good mechanical bond and resist internal wear, it is unnecessary to fill the voids completely. If the stone is weak, it is necessary to use water for filling in the voids with additional fines.

Claybound bases are a common modification in some countries. The constituents are gravel, sand and clay. This base is sealed. If used without a surface course, deliquescent chemicals may be beneficially added to preserve moisture content and aid maintenance.

- (h) *Soling or pitching*.—Heavy soling has been employed extensively upon airfields in operational areas where experienced labour has been abundant, and sub-grade soil of a treacherous or unstable type.

Slow rate of construction and heavy transport demands commonly rule out this class of base course under war conditions.

- (i) *Special stabilizers*.—Considerable experimental work has been done upon special water-repellent materials. The most promising is a type of fine, powdered resin ("Vinsol"), which is mixed into the soil either directly or, in smaller proportions, mixed with a weak alkaline solution to form an emulsion with water. It is hoped that this and similar methods may be suitable for a wide range of soils and that results of practical value will be obtained with very small tonnages of imported material (e.g., 1.5 lb. of Vinsol per square yard, for a favourable soil).

Other products which have been used or tested are certain waste products from the wood-pulp industry, and molasses.

#### SECTION 74.—SURFACE COURSES

1. A runway surface course must be :—

- (a) Smooth, true to grade and, for all-weather airfields, waterproof.
- (b) Reasonably non-slippery.
- (c) Free of dust, liable to be harmful to engine parts and to impair visibility.
- (d) Free of chippings or heavy grit, injurious to propellers and tyres.
- (e) Supported by a strong sub-grade with or without the addition of a base course.

2. A classification of the principal surface courses and prefabricated surfacing materials is given below :—

- (a) *Open steel mats*, of widely varying weight and bearing strength, which, used alone, do not protect the sub-grade from softening by rain.
- (b) *Prefabricated waterproof mats*, which preserve the natural strength of the sub-grade and provide a smooth, dust-free surface.

- (c) *Bitumen, tar or emulsion*.—Grouting methods with stone and gravel.
- (d) *Bitumen, tar or emulsion*.—Plant mix with
  - (i) Sand.
  - (ii) Stone.
- (e) *Cement*
  - (i) Concrete.
  - (ii) Cement grout (Colcrete).
  - (iii) Soil-cement.
- (f) *Stabilization methods*.—Effective under favourable climatic conditions.
- (g) *Natural surfaces*.—Turf, sand and other soils.
- (h) *Miscellaneous*.—Including bricks, coral, timber.

3. Plant and materials suitable for any of these technical methods will be provided commonly in the light of information gained long before any detailed examination of the theatre of war concerned. In general the choice of specification, at a given time and place, will rarely present a difficult problem to the engineers in the field. Practicable alternatives will be few.

Speed and efficiency are commonly associated with repetition methods, in which airfield units have gained skill and confidence by experience. There is little opportunity for experiment and change in the fulfilment of hasty war-time tasks.

## CHAPTER 10

### PREFABRICATED RUNWAY MATS

#### SECTION 75.—GENERAL

1. In the design of portable landing mats, to meet forward operational requirements, a number of objectives have been kept in view. Some demands are conflicting, their relative importance varying with the physical and tactical conditions associated with particular tasks or regions.

2. The factors influencing test and development of steel types have been:—

- (a) *Strength*. The mat should be flexible enough to conform to normal undulations and rigid enough to bridge local inequalities. Heavy panel types should have connections capable of transferring the load from one panel to another.
- (b) *Surface*. Free from dangerous projections, even after considerable wear.
- (c) *Rapidity of laying*. The target arbitrarily chosen, for the lighter types, has been the laying of 1,000 by 50 yards in one day, with trained men.
- (d) *Repair*. Damaged sections should be capable of ready replacement.
- (e) *Weight and cargo space*. Minimum obviously desirable.
- (f) *Freedom from skid*, when wet or muddy.
- (g) *Tyre wear* should be not unduly increased.
- (h) *Speed of production* to be satisfactory.
- (i) *Good camouflage characteristics*.
- (j) *Maintenance moderate and high salvage value*.
- (k) *Moderate demands for preparation of subsoil*.

- (g) *Macadam base*.—Dry, waterbound or bituminous grouting.

This is a high quality base, built of angular crushed stone or crushed slag in layers 3 to 5 inches thick. A base of this construction, to meet heavy static requirements, would represent a surface course under operational conditions, with the addition of a suitable seal coat.

With dry-bound macadam, if the stone is hard enough to permit good mechanical bond and resist internal wear, it is unnecessary to fill the voids completely. If the stone is weak, it is necessary to use water for filling in the voids with additional fines.

Claybound bases are a common modification in some countries. The constituents are gravel, sand and clay. This base is sealed. If used without a surface course, deliquescent chemicals may be beneficially added to preserve moisture content and aid maintenance.

- (h) *Soling or pitching*.—Heavy soling has been employed extensively upon airfields in operational areas where experienced labour has been abundant, and sub-grade soil of a treacherous or unstable type.

Slow rate of construction and heavy transport demands commonly rule out this class of base course under war conditions.

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- (b) *Surface*. Free from dangerous projections, even after considerable wear.
- (c) *Rapidity of laying*. The target arbitrarily chosen, for the lighter types, has been the laying of 1,000 by 50 yards in one day, with trained men.
- (d) *Repair*. Damaged sections should be capable of ready replacement.
- (e) *Weight and cargo space*. Minimum obviously desirable.
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- (i) *Good camouflage characteristics*.
- (j) *Maintenance moderate and high salvage value*.
- (k) *Moderate demands for preparation of subsoil*.

In practice, the two considerations of first importance, have been weight (dead and shipping) and speed of laying, with due regard to preliminary work on sub-grade. The relative utility of different types of steel runway which have survived the test of time is roughly proportional to the weight of metal per unit of runway area, with its adverse influence upon problems of supply.

3. Later experiments have led to the development of a Hessian mat, in which waterproofing and good wearing qualities are combined in a product of light weight, which can be laid speedily upon a well-compacted surface.

#### SECTION 76.—STEEL MATS

1. All light types of steel mat are intended for hasty service upon fighter airfields and are designed for use in favourable climates, with a minimum of base preparation. They are suitable for hard service only when laid on strong turf or well-drained sub-grades, such as sand or gravel. Their use is very limited on other bases, when their inherent structural weakness rapidly shows up under heavy traffic.

2. The heavy types are sometimes used as a surface course, upon airfields for heavy aircraft. A substantial thickness of selected base-course material is essential upon impermeable soils in wet weather, or upon a yielding sub-grade, not capable of good compaction.

3. The grid types of mat (*e.g.*, bar and rod) are superior to planks (P.S.P.) in that they are less conducive to skidding when wet and muddy. They also present a considerably smaller area of exposed surface, which is a desirable feature when camouflage considerations are important. Bar and rod is also lighter than P.S.P. and Irving Grid, per unit of area covered.

P.S.P. is less bulky to handle, is stronger, and is more suitable for use upon a yielding or undulating foundation. With the need for standardization, P.S.P. presents further merits in more rapid and simple production and, although single plates can be easily damaged, inspection, at the factory or in the field, is simple.

From the important aspect of shipping tonnage P.S.P. is preferable even to the light Sommerfeld Track when provided with coir matting as an under-carpet.

Table VII.—Characteristics of steel landing nets

	Square Mesh Rolls	Square Mesh Panels	Sommer- feld Track	Heavy Bar and Rod	Pierced Steel Plank	Irving Grid
Dimensions ..	77 ft. 3 ins. × 7 ft. 3 ins.	12 ft. 3 ins. × 6 ft. 3 ins.	75 ft. × 10 ft. 7½ ins.	12 ft. × 3 ft.	10 ft. × 15 ins.	12 ft. 6 ins. × 22½ ins.
Weight per sq. ft. ..	1½ lb.	1½ lb.	1½ lb.	3½ lb.	5½ lb.	5½ lb.
Weight per sheet ..	547 lb.	80 lb.	900 lb.	140½ lb.	63½ lb.	129 lb.
Per runway— 1,000 yds. × 50 yds.						
3-ton lorry loads ..	150	85	128	250	400	
Shipping tons ..	655	308	500	1,040	525	1,054
Laying speed, sq. ft. per man/hr. ..	80	100	175	70	110	70

4. A.R.C. steel mesh, used in the Pacific areas, is similar to B.R.C. or square mesh track in characteristics. A.R.C. is 3-inch by 3-inch mesh, and weighs 1½ lb. per square foot.

5. Light wire tracks, in rolls and panels. Sommerfeld track superseded Army track, a woven wire net with diagonal mesh, which tended to billow dangerously after use and required pickets and holding-down discs for every roll. Square mesh track has now largely superseded Sommerfeld. Square mesh in rolls is also liable to billowing, but in panels this fault is not displayed. The panel type of square mesh represents the best available open-mesh tracking within the limited range of service inevitable for a weight of 1 lb. of steel per square foot of coverage. It is not laid as rapidly as Sommerfeld track, but for loading into ships or lorries it is far more favourable. Panels are also less liable to distortion than rolls.

## SECTION 77.—PIERCED STEEL PLANK

1. P.S.P., sometimes referred to as Marston or Universal track, has been the most widely used of all types of portable landing mats developed during the war. P.S.P. runways have been made, under tropical and arctic conditions, for all weights of aircraft, and upon soils of widely variant bearing capacities. It has finally superseded the two other well-known types of comparable merit—Irving Grid and Heavy Bar and Rod—as the standard mat of American production.

### 2. Practical details :—

- (a) The planks, stamped or rolled from 10 gauge mild steel plates, are 10 feet long and 16 inches wide overall, giving a coverage of 15 inches.
- (b) Apertures for reducing weight are  $2\frac{1}{4}$ -in. diameter in three rows, and running between them are two pressed troughs  $\frac{3}{4}$  inch deep, to give rigidity.
- (c) Planks have been shipped in bundles of 30 and 20. These break down into sub-bundles of five panels, containing two 5-ft. half panels and four full panels.
- (d) In transporting and laying out, care must be exercised not to damage individual planks, especially the bayonet hooks or teeth. The steel is soft and easily bent. Repair of teeth,  $2\frac{1}{2}$  inches long, is easy, but wastes time.
- (e) When the teeth of one plank are placed into the slots of the next, and fully engaged by lateral movement in the direction of the toe, a space of  $1\frac{1}{2}$  inches is left into which a locking spring-clip of  $1\frac{1}{4}$  inches is fixed with a light hammer. A clip is used in the second slot from the end of each plank. The flat side of the clip is placed towards the bottom plank at the overlap.
- (f) Although work appears so simple, good organization and training are essential for good alignment and rapid progress. The planks must be correctly stacked along each side of the runway and subsequently laid out across the site exactly as required for fixing, with the teeth of one row all in one direction and the teeth of the next all in the opposite direction.

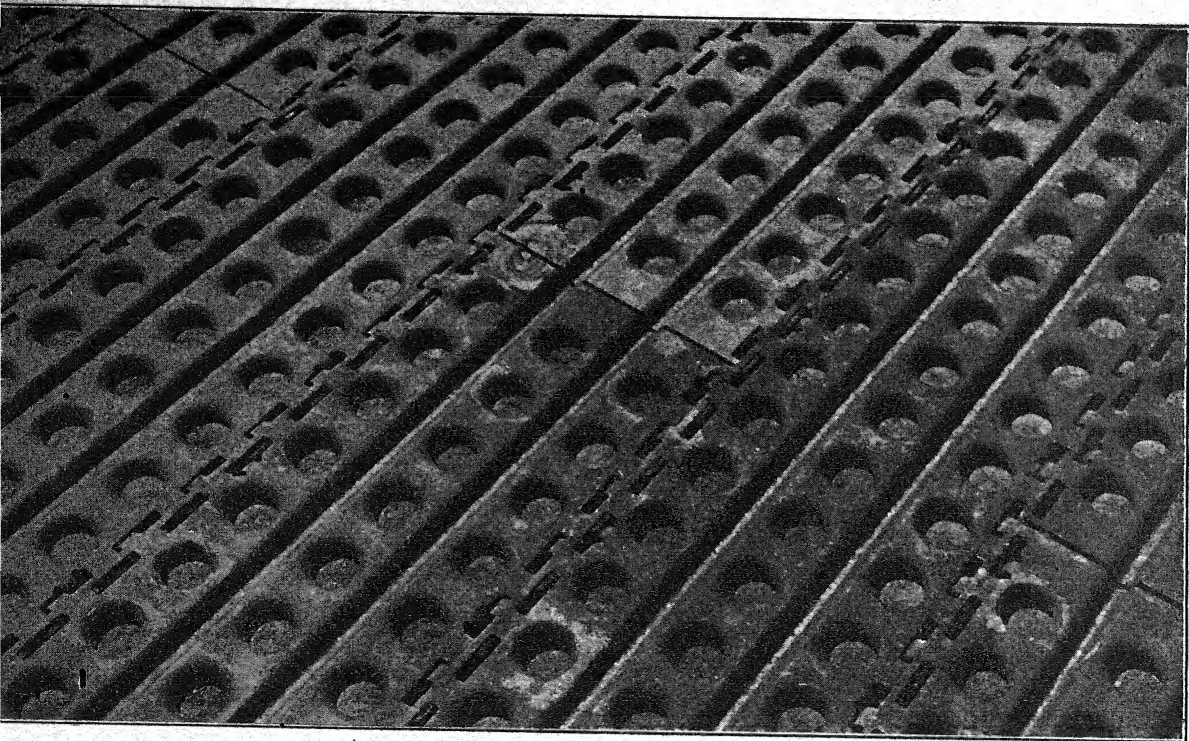


PLATE 24.—P.S.P. CONNECTED TO FORM A RUNWAY (ENGINEER BOARD, FORT BELVOIR, VIRGINIA)

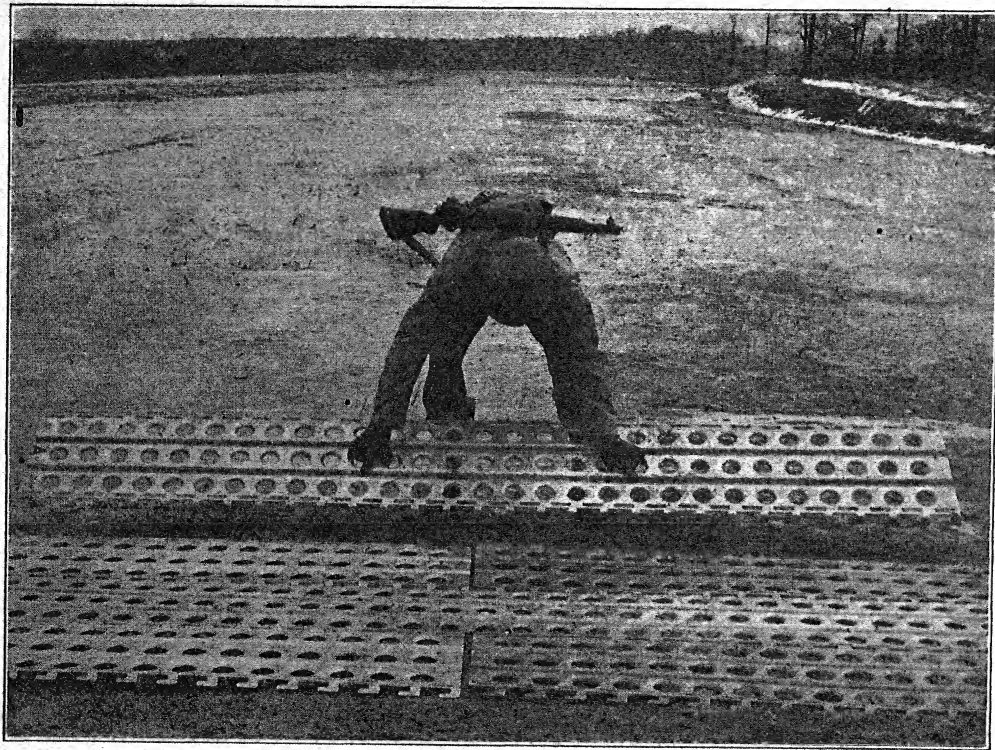


PLATE 25.—P.S.P. SHOWING PLACING OF A PANEL (ENGINEER BOARD,  
FORT BELVOIR, VIRGINIA)

3. **Laying** starts with one full row across the middle of the runway, care being taken to have the centre joint exactly on the longitudinal centre line, and the row of planks laid accurately at right angles. Irregularities may be hard to correct later.

- (a) Subsequent rows, working only from the transverse centre line to avoid the difficulty of joining two approaching strips, are laid outwards by two parties.
- (b) Alternate rows are staggered or "stretcher-bonded," leaving a gap of 5 feet at each end of alternate row, to be filled by 5-foot planks if available.
- (c) Two methods of locking successive rows are possible :—
  - (i) The "shingle system," each plank being under and over, or
  - (ii) alternating, with one plank under and the next over. The latter, though slightly slower, is the right method. It enables blocks of planking to be more easily removed for replacement or sub-grade repairs.
- (d) Planks are laid continuously in echelon across the site, starting from one side of the runway. A working edge in the form of a "V" has also been found effective and is reported to have resulted beneficially in any jams or gaps occurring near the edges, where they are more easily rectified than near the centre line.
- (e) Alignment of the mat is controlled by staking the centre line of the runway and checking the joints by eye. If the mat tends to work to either side, the error must be corrected by pulling the mat into position by means of a truck or tractor. If the fault is caught early, the loss of alignment can probably be corrected by levering the section over by means of crowbars inserted through the holes in the plank. (See Appendix IX for alternative method of laying.)

4. **Labour and speed of work.**—Access to site permitting, it should always be possible to unload mats direct from trucks, at proper intervals alongside the runway, to ensure minimum carry and to maintain correct stacking ahead of laying. If the soil is too soft for this transport, it will be too soft for the laying of steel mats.

Excluding men employed upon transport, unloading and stacking, the labour force will be distributed, as under, for each face :—

Laying crews, including carrying, laying and clipping	25
Crowbar men	3
Band and wire cutters on bundles	2
Short planks (5 feet)	2
Rakers and finishers ahead of mat	8

A total of 40 men, with 6 or 7 N.C.Os.

Average rate of constructing a 50-yard track may be taken at roughly 200 yards per day, with two faces in progress outward from the middle of the runway.

**5. Competitive laying of P.S.P.**—A competition held in U.S.A., between two engineer units, led to the following results :—

Two companies each took one half of a runway, 4,380 feet by 150 feet or 657,000 square feet, to be laid alongside an existing Sommerfeld track.

The maximum number of men used at a time was 57 and the average working party was 40 men.

The winning company finished the task (730 yards of runway) in 60 hours 15 minutes, including 3 hours 5 minutes lost on account of flying operations.

Total working time ... ..	57 hours 10 minutes
Total area ... ..	323,932 square feet
Total man-hours ... ..	2240·5
Square feet per man-hour ... ..	144·5

The other company recorded 141·9 square feet per man-hour.

Weather conditions were unsettled. For night work, acetylene lamps were used by one company and a portable electric generator by the other.

**6. General.**—If P.S.P. is laid on a natural soil surface of low bearing strength, for rapid use in operations, it can be classed only as a temporary expedient. Longitudinal corrugations are soon caused by heavy traffic, and pockets develop under the mat, in which water collects. The movement of aircraft across the mat creates a pumping action, forcing water and mud through the holes on to the surface, which becomes dangerously slimy and slippery. Considerable settlement of mat will also take place over the soft patches. Makeshift methods of forcing gravel through the holes to build up the sub-grade have proved unsuccessful. A more stable base can be laid, section by section, when it is practicable to put a runway out of service intermittently. The track is opened up, across the whole strip and rolled back sufficiently to allow stone or sand to be put down as a base course. An instance is on record of raising a track 6 inches by night work only.

The most satisfactory method of attaining strength and durability is by laying track on a porous base course. Below this should be a well-levelled and graded formation, with a crown of about 9 inches or transverse gradient of 1 : 100.

A 6-in. bed of permeable sand should be provided ; up to 18 inches have been used upon one important runway laid on bad "cotton-soil." Hardcore, gravel, broken brick, coral, and other materials, well consolidated, have also been used successfully. In most cases, when such bases are used, effects of rain are beneficial. But the time taken to complete a runway, which may be two or three weeks, is excessive for early requirements in an offensive, and some other expedient is generally essential.

When the surface immediately below P.S.P. is loose, and tends to blow away under the action of slipstreams, a suitable surface can be produced by the application of an oil spray.

**7. Sub-grade and base requirements.**—P.S.P., upon certain soils, exercises a retarding influence upon the drying out of excessive moisture. Bases over impervious sub-grades act as water reservoirs. The mats tend to accumulate rain water at the low end of individual planks and to a smaller extent through the holes. Transverse grades upon impermeable soil should be set at the maximum allowable slope (1 in 60) to accelerate drainage.

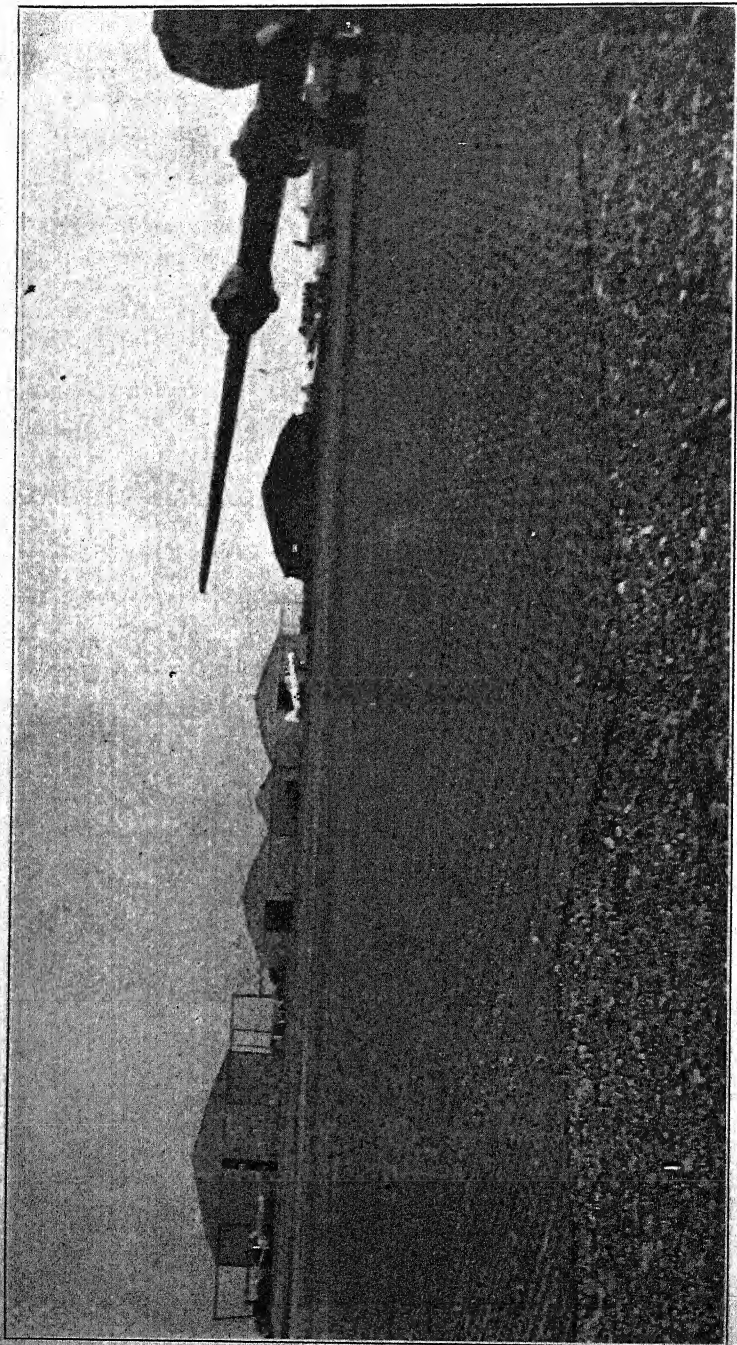


PLATE 26.—P.S.P. RUNWAY, WITH GRAVEL UNDERLAY UPON LOAMY SOIL, ALGERIA, 1943

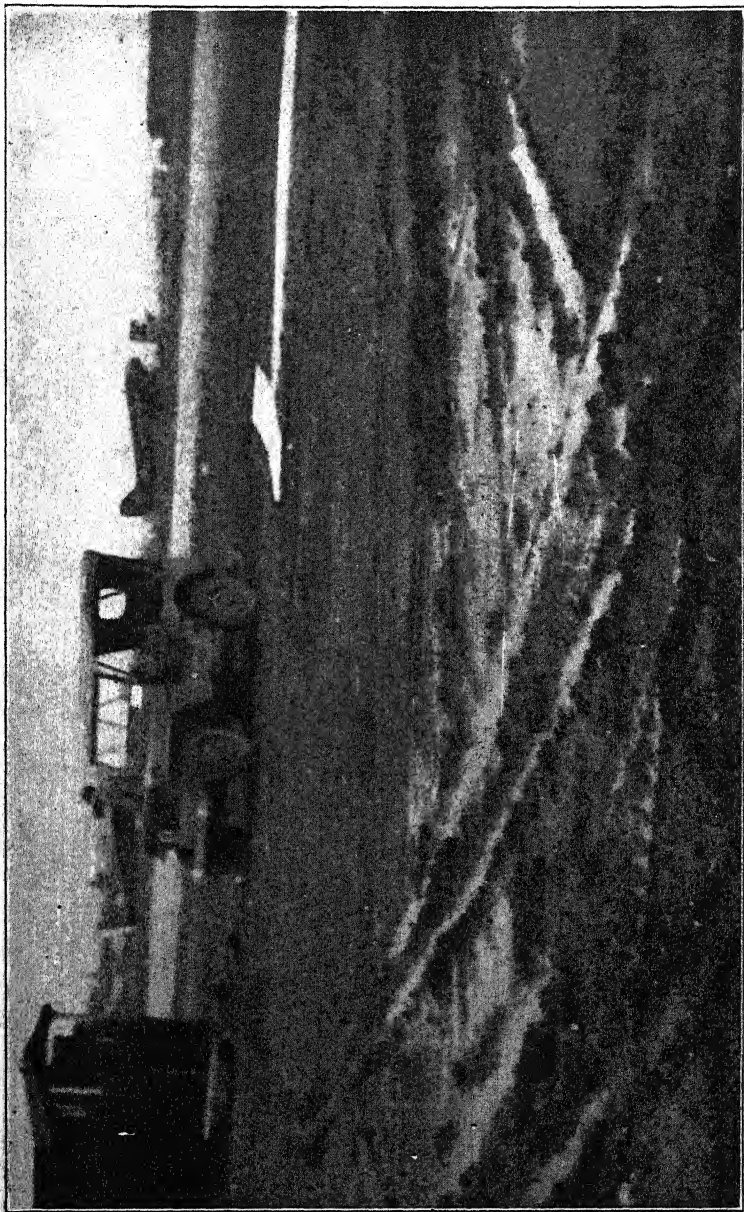


PLATE 27.—SOIL CONDITIONS ADJACENT TO P.S.P. RUNWAY, ALGERIA, 1943

Thicknesses of base course under P.S.P. have been estimated, for guidance, on a broad assumption of saturated conditions and a year's service :—

Table VIII.—Thickness of base course under P.S.P.

Sub-grade soil	Thickness of base course	
	Fighter	Medium bomber
Gravels, gravelly sands, clean sands, and silty sands ... ..	Nil	Nil
Poorly compacted silts, clayey sands, and soils with low plasticity ... ..	Nil	4 ins.
Fairly stiff clays, sandy clays, lean clays, organic silts ... ..	6 ins.	10 ins.
Clays and silts, when poorly compacted or in a state of low density ... ..	12 ins.	20 ins.

The maximum figure of 20 inches given in column 3 agrees with practice adopted upon an important airfield in North Africa.

**8. Anchoring of mats.**—Both the pierced steel plank and heavy bar and rod types of mat tend to warp at the edges of runways and taxi-tracks when subjected to heavy traffic near the edge. For granular and non-cohesive soils, a "V" ditch 2 to 3 feet deep is excavated along the edge of the runway or taxi-way with a motor grader. A runway can be adequately anchored by omitting the 5-foot or half planks along the sides and bending the projecting planks at the 5-foot point into the V-ditch, backfilling and compacting the soil. Bending is effected by placing a 2-in. by 4-in. plank below the plates and running over the ends with a loaded truck or a motor grader.

Short screw-type anchors and long angle-iron pickets are also used for pinning down the ends of the planks, methods adopted being governed by soil consistency. Pickets used successfully in a relatively firm clay, consisted of 2-in. by 2-in. by  $\frac{1}{4}$ -in. angles, 3 feet 6 inches long, driven through the outer hole of the plank. The ridge of the picket was split  $4\frac{1}{2}$  inches from the top; 4 inches of one strip was bent over 90 degrees, pointing outward to form a cap and the other 180 degrees to be safely below the surface.

The mat can also be held down by placing a pierced steel plank, with a screw-type anchor at each end, across the projecting ends of alternate planks, but this method would only be used, in practice, where ditching is difficult. An alternative method is to picket a Sommerfeld track lacing bar along the edge of the track.

The ditching method is more generally applicable, but is unsatisfactory when it is expected to salvage the planks for use upon another airfield. P.S.P. is difficult to restore to shape when bent. Damaged planks will usually be cut to produce a 5-foot section, for use in filling the ends of rows.

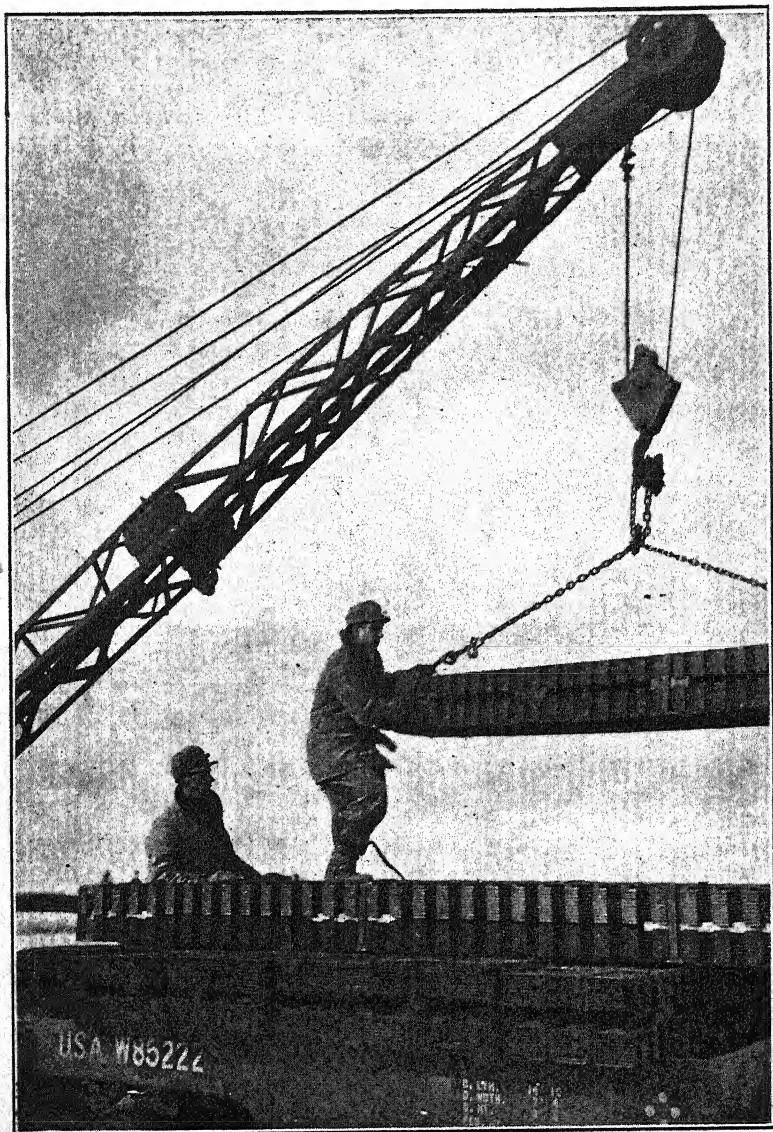


PLATE 28.—UNLOADING BUNDLES OF P.S.P.

9. **Temperature changes.**—In certain climates allowance will be made for temperature changes. If a rise of 50 to 100 degrees is expected, the planks are pulled as far apart as the bayonet hooks allow and the extra width of the connection slots will then provide the necessary leeway for expansion. For an expected heavy fall in temperature, planks will be pushed tight together, allowing slack to be drawn up by contraction.

10. **Pierced steel plank repairs.**—A rehabilitation unit, suitable for overseas theatres, has been developed in America, for straightening, rolling, cleaning and painting P.S.P. reclaimed after service.

Badly bent planks are first roughly straightened by hand on a special frame and then fed to rolls, for removal of all deformations except for twisted bayonet joints. Planks are cleaned by means of mechanically operated rotary brushes. After bayonets have been straightened, the planks are passed to the paint unit, consisting of a heated alkali bath, a hot water rinse, a tank of paint, and drying ovens.

A unit capable of handling 200 to 250 planks per hour weighs under 25 tons, or 50 tons shipping weight.

## SECTION 78.—SQUARE MESH TRACK

1. **General.**—Square mesh track is supplied in two forms, rolls and panels. The standard mesh is 3 inches by 3 inches, using 5-gauge cold-drawn steel with fuse-welded intersections.

Rolls have a diameter of 25 inches and weigh 547 lb., and when unrolled have a length of 77 feet 3 inches. Shipping space,  $27\frac{1}{2}$  cubic feet.

Panels are 12 feet 3 inches long and weigh 80 lb. They are shipped in bundles of four. Shipping space for each bundle is 7.7 cubic feet, which is equivalent to approximately half that of the roll per unit area.

More factory work per unit of area covered is involved in the production of panels, which are 6 feet 3 inches wide as compared with 7 feet 3 inches for tracking in rolls.

Both types are connected, upon laying, with "B.R.C. clips," 8 inches long by 2 inches wide, pressed from  $\frac{1}{8}$ -inch steel plate, and packed in bundles of 25 weighing 18 lb.

Pickets used for pinning down the outside edges of the track are of standard Sommerfeld type, made up in bundles of 10, weighing 55 lb. for the 2-foot picket and 82 lb. for the 3-feet.

Comparative tests have been carried out upon the two forms of track, establishing the practical superiority of panels, particularly for active service conditions. From the aspects of shipping space, lorry loading, handling, retention of shape, and laying, panels are superior. After use, panels are less liable to deformation and billowing than rolls.

Laying times are difficult to compare without qualification. Panels are easier to manipulate and laying parties of average experience attain higher speed than with rolls. It is probable, however, that with special training, with rolls in good condition, and with favourable working conditions, this superiority might be reversed.

A rough estimate of 100 square feet per man-hour can be taken provisionally.

## 2. Laying procedure

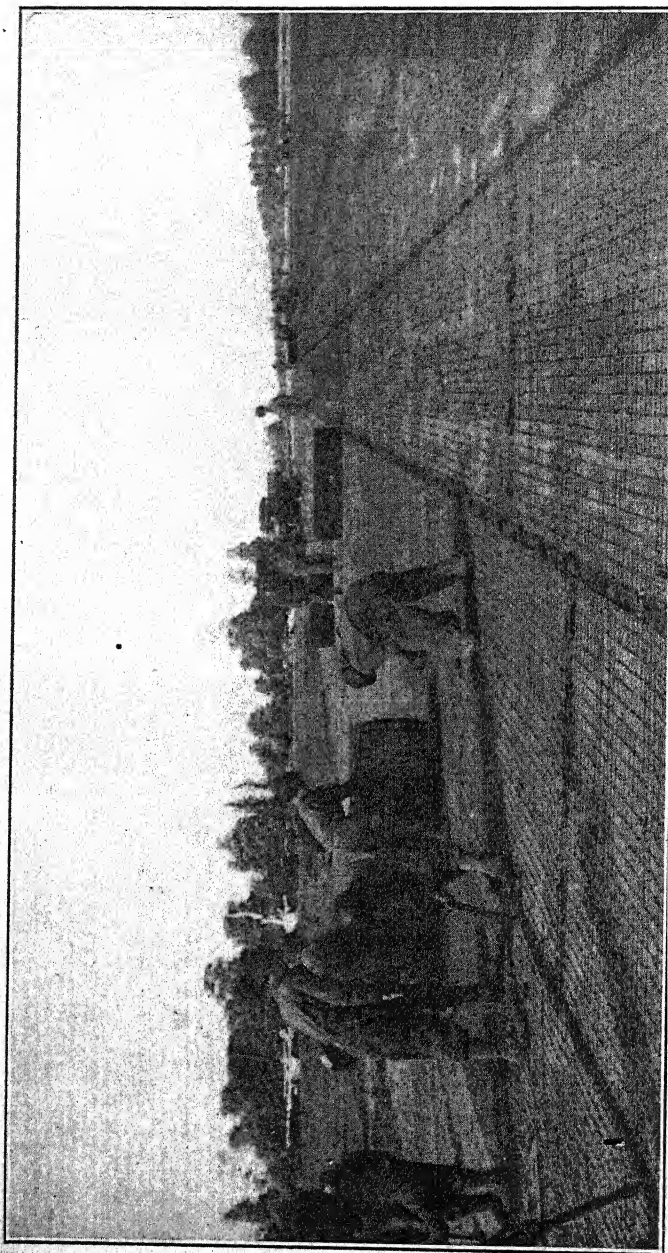
### (a) Panels

- (i) On a strip 40 yards wide, 20 panels are used per row. Laying starts along the transverse centre or base line, outwards from the centre line, in both directions toward the edges. Panels are laid, with the longitudinal bars up, staggered alternately, 1 foot 6 inches from the base line. When the first row is complete, work can start on opposite faces working towards both ends of the runway in a "V" formation, transverse and longitudinal connections being clipped as the work progresses. The transverse joints overlap 3 inches.
- (ii) Clips are inserted at 18-in. centres, and pickets 2 feet or 3 feet long along the edges of the runway at 4-foot centres.
- (iii) Exclusive of truck drivers, the loading and laying parties comprise :—
 

Loading and unloading	...	2 N.C.Os.	24 men
Laying	...	10 "	160 "
Unwiring bundles: pickets;			
general	4	"	22 "
	16	"	206 "
- (iv) The N.C.O. in charge of unloading is made responsible for the correct stockpiling of panels and accessories along both sides of the runway.
- (v) The 160 men, on laying, are divided into 40 squads of four men each, providing 20 squads to work outwards on each side from the centre. Men Nos. 1 and 2 carry panels and place in position; No. 3 inserts clips; and No. 4 carries and distributes clips, and performs odd duties.

### (b) Rolls

- (i) For a runway, 40 yards wide, 1,200 yards long, 18 rolls are used for the width and 47 for length, making a total of 846 rolls.
- (ii) Work proceeds on similar lines as with panels, across the transverse centre line as a base, with ends of tracking staggered 4 feet alternately. The first rolls must be accurately placed and temporarily picketed to avoid curling. After a roll has been completely extended, timber is placed  $1\frac{1}{2}$  feet from the end. Working party then stands on the end of the roll and kneads the mesh with their feet to make it conform to the ground. This measure may have to be taken at other points when the track is being unrolled. The next roll is then jockeyed into position and clipped transversely to the first.
- (iii) Work proceeds outwards from the transverse centre line in "V" formation.



(iv) All overlapping is 6 inches (two meshes) both longitudinally and transversely.

(v) Clips are inserted as follows:—

*Transverse joints.*—At 1-foot centres in outside mesh of top roll and at 2-feet centres in second mesh of top roll. Clips are staggered.

*Longitudinal joints.*—At 18-inches centres in outside mesh of the top roll and at 3-feet centres in second mesh of top roll. Clips are staggered.

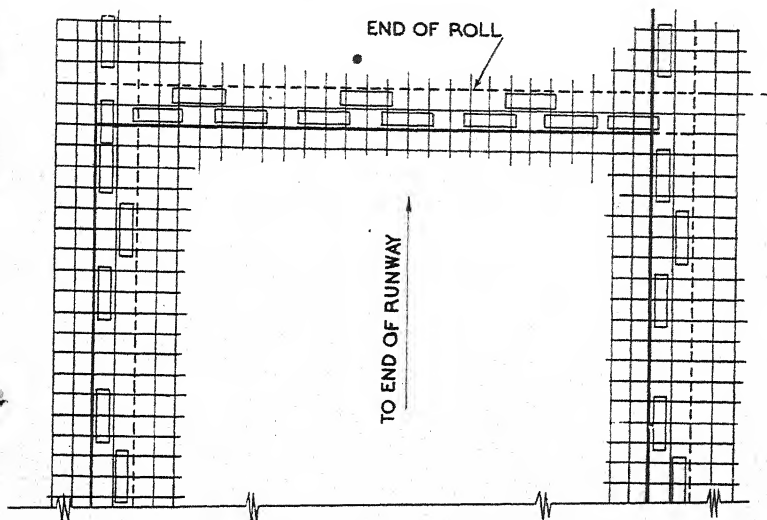


PLATE 30.—S.M.T. ROLLS, POSITION OF CLIPS

- (vi) Pickets of Sommerfeld type are driven in at 3-ft. 6-in. centres along the edges of the runway.
- (vii) At the ends of runway the fabric is bent down into a shallow trench, picketed and the trench back-filled.
- (viii) It is important to see that the fabric runs true and square otherwise kinks will occur.
- (ix) The prevention of billowing is a major consideration with this track and the best method appears to be as follows: Make the transverse joints for four consecutive rolls in any one line, and tension the four lengths in a longitudinal direction by pulling with a winch lorry. When irregularities are taken out drive in two Sommerfeld pickets per roll, one at the centre and one at the end of the roll along the longitudinal joint. Then insert clips along longitudinal joints.
- (x) If a winch lorry is not available, straining can be done by hand or crowbar as unrolling proceeds and temporary pickets driven in along the centre line of the roll at about 9-ft. centres to hold this tension. All pickets except one at the centre and one at the end can be removed when the laying of the roll is complete.

- (xi) Small billows can be removed by crimping.
- (xii) It is important that the hooked ends of the clips engage fully around a member of the lower of the two rolls being clipped.

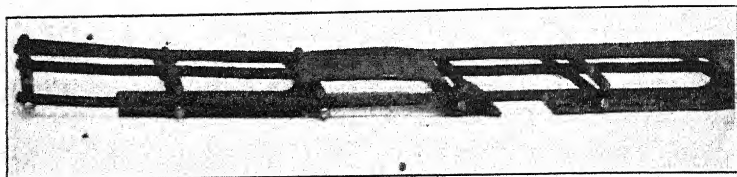


PLATE 31.—S.M.T. CLIP IN CORRECT POSITION

**3. Typical laying method** (North West Europe).—Work started from the middle of the strip and proceeded towards both ends. Centre rolls were strained in both directions and work proceeded from the centre line outwards. Work was therefore proceeding on two faces towards each end of the runway, *i.e.*, four faces in all. Two parties of 70 men each were employed—one working towards each end of the runway. Straining was done every 100 yards, *i.e.*, every four rolls.

(a) Each party was organized as follows :—

					Total
4 unrolling parties, each of 6 men	...	.....	...	...	24
4 clipping parties, each of 8 men	...	...	...	...	32
1 picketing party of 6 men	...	...	...	...	6
1 N.C.O. I.C. party	...	...	...	...	1
1 N.C.O. controlling each winch lorry	...	...	...	...	2
1 N.C.O. at end of mesh	...	...	...	...	2
1 salvage party of 3 men	....	...	...	...	3
					—
Total personnel					70
					—

(b) Drill for two unrolling parties and two clipping parties was as follows :—

- (i) First unrolling party lay first 100 yards, and after tensioning lay second 100 yards.
- (ii) Second unrolling party start from the base line and lay their first 100 yards while first party are laying their second 100 yards.
- (iii) On completion of second 100 yards first party return to the base line and repeat.
- (iv) Second party does likewise.
- (v) When full width of runway is complete to 200 yards length the procedure is repeated for every 200 yards.
- (vi) Clipping parties follow their respective unrolling parties.

Subject to conditions on the site a further 70 men will probably be required for loading, unloading and carrying rolls. Cranes are desirable for loading and unloading.

## SECTION 79.—CHANNEL TRACK

1. Channel track is a comparatively lightweight and flexible steel surfacing, capable of rapid laying, for the construction of runways on soft or loose ground.

It functions as a grillage spreading the applied load over the ground. The flexibility and strength is such that it will conform, under load, to minor irregularities in the configuration of the ground without diminishing its load carrying capacity.

2. The track consists of composite panels, made from two layers of light gauge cold formed bars, joined together transversely, by interlocking the projecting ends of the bottom bars, and secured with clips; longitudinally they are joined by means of shaped joint covers.

3. Component parts of the track comprise :—

- (a) *Panels*.—6 feet long by 11 feet wide, weighing 180 lb. They are composed of a number of cold formed mild steel lengths of channel section with flanges, projecting at right angles, made from 18-gauge strip. The bars, which are  $\frac{3}{4}$  inch deep and  $2\frac{1}{2}$  inches wide over flanges, are placed at right angles, flange to flange, at about 5-inch centres, and riveted together with two rivets at each intersection to form a rectangular grid. Openings about 3 inches square are thus left between the bar flanges. Supplied in bundles of 10, 40 panels can be carried in a 3-ton G.S. lorry. Single panels are loaded and unloaded by six men (four on the ground, two in the lorry). Damage to panels during transit may be corrected by the use of a rectifying tool, provided on a scale of 60 per airfield.
- (b) *Joint covers* are pressed from 18 gauge mild steel, and are used to form the longitudinal joint between panels. They envelop the bar section and have projecting lugs which are crimped round the bar flanges. Two types are used for runways :—
  - (i) *Large* : 12 inches long,  $2\frac{1}{2}$  inches wide,  $1\frac{1}{2}$  inches deep over lugs, weighing 0.78 lb. each.
  - (ii) *Small* :  $7\frac{3}{8}$  inches long,  $2\frac{1}{2}$  inches wide,  $1\frac{1}{2}$  inches deep over lugs, weighing 0.47 lb. each.
- (c) *Spacing clips* are used to retain rows of panels in their correct relative positions longitudinally, preventing movement under action of traffic. They function as compression members, and are constructed of 18 gauge mild steel. They are fixed by closing the lugs with the small closing tool. 8 inches wide by  $6\frac{1}{2}$  inches long they weigh 0.85 lb. each.
- (d) *Pickets* are required to assist in holding down the longitudinal edges of the runway.

4. Tools required for laying the track

- (a) *Closing tool, large*—used for closing the lugs of large joint covers. Weight 18 lb.
- (b) *Closing tool, small*—used for closing the lugs of the small joint covers and spacing clips. Weight  $6\frac{1}{2}$  lb.
- (c) *Joint cover opening tool*—used for removing large and small joint covers, and spacing clips when extracting panels or dismantling runway. Weight  $1\frac{1}{2}$  lb.

- (d) *Panel spacing tool*—used in pairs when laying the track with the object of spacing panels at their correct distance apart longitudinally. Also used for extracting panels. Weight  $10\frac{1}{2}$  lb.
- (e) *Rectifying tool*—used to rectify the shape of projecting ends of bars, which may have been deformed in transit. Weight  $1\frac{1}{2}$  lb.
- (f) *Lever jacks*—provided on a scale of 12 per runway they are used to facilitate the removal and replacement of damaged panels. Weight 50 lb. each.

### 5. Laying—method of placing the panels

- (a) Panels are laid with the 11-ft long bars on top, running transversely to the direction of traffic. These bars are connected to the similar bars of the panels on each side by means of joint covers, which are fixed by crimping their lugs with the large closing tool. Large joint covers are used at the joints of all transverse bars, except the end bars of panels, for which small joint covers are provided.
- (b) The lower bars of panels project so that the transverse joints in the track can be formed by interlocking panels when laying.
- (c) To ensure that the pitch of the transverse bars on either side of the joint is the same as the normal pitch, spacing clips are inserted as laying proceeds.
- (d) The interlocking of the bars requires the panels to be offset relative to each other for a distance equal to half the pitch of the bars.

### 6. Laying drill

- (a) The following organization was adopted in the United Kingdom for the trial laying of a runway, 10 panels wide, working outwards from the transverse centre line to the ends of the runway.
  - (i) Set out longitudinal centre line and edges of the runway.
  - (ii) Set out and mark transverse centre line exactly at right angles to the longitudinal centre line of the runway. (A small error in location will appreciably affect the bearing of the runway.)
  - (iii) Stack panels as delivered, in piles on site of runway (see Plate 32).

The working party required for laying out panels is:—

Party	Number employed per party	Number of parties per runway	Total per runway
N.C.O. I.C....	1	4	36
Off loading on lorry	2		
Stacking on ground	4		
Uncrating ...	2		

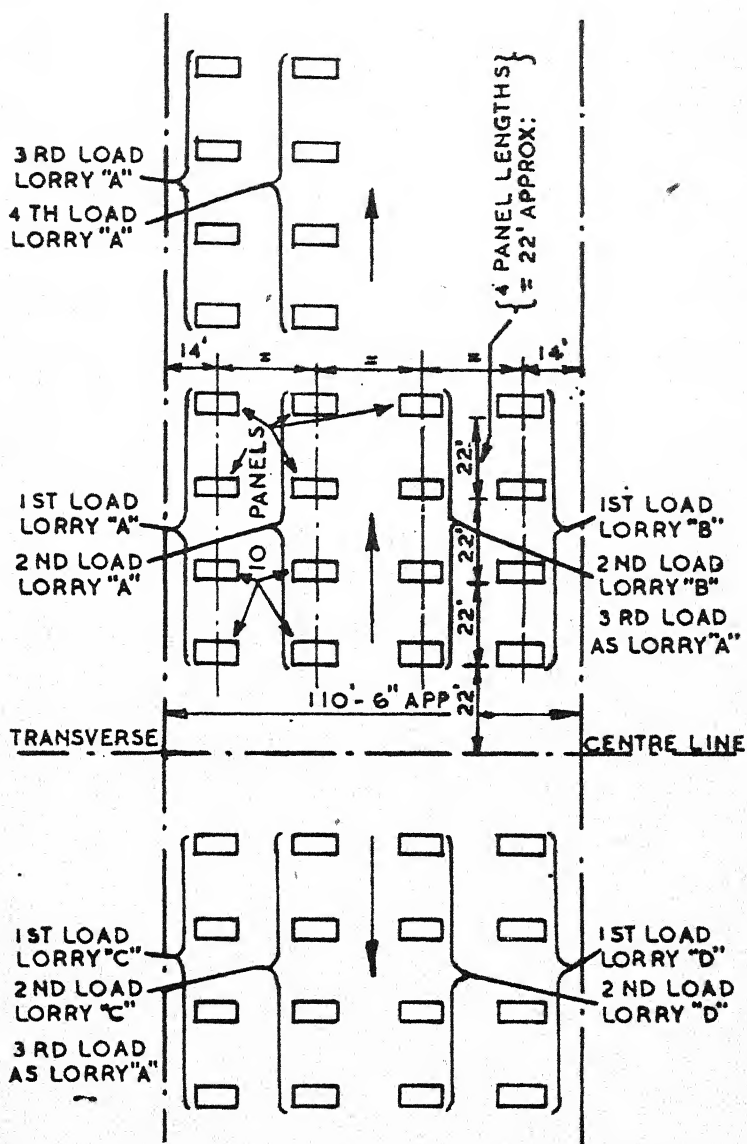


PLATE 32.—CHANNEL TRACK—STACKING OF PANELS.

- (iv) Excavate trenches along both sides of runway to the dimensions shown in Plate 33. If panels have not been stacked before track laying commences, side trenches should be excavated as stacking proceeds, otherwise they will interfere with the access of lorries to their off-loading points on the runway.

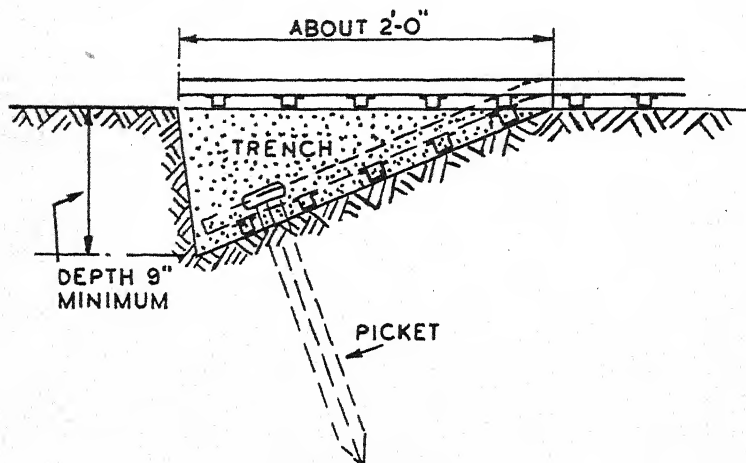


PLATE 33.—EDGE TREATMENT OF CHANNEL TRACK.

- (v) Detail track laying parties as follows :—

Serial No.	Duty of party	Number employed per party	Number of parties per runway	Total number employed per runway	Remarks
1	N.C.O. I/C Lifting panels from piles and into position. Spacing panels panels	1 4 2	4	28	These parties are marked "A," "B," "C" and "D" in Plate 34.
2	Fixing joint covers, large and small	9	2	18	One man per longitudinal joint.
3	Spacing clip fixing	2	4	8	
4	Picketing	2	4	8	
5	Distributing clips, pickets, etc., to working parties	2	2	4	Two light lorries or jeeps required.

- (vi) Allocate panel laying parties "A," "B," "C," and "D" on runway as shown in Plate 34.

(vii) Issue parties with tools as shown below :—

Party serial No.	Tool	Number per party	Number per runway
1	Tools, closing, large ... ..	1	4
	Tools, opening ... ..	1	4
	Tools, spacing ... ..	2	8
2	Tools, closing, large ... ..	9	18
	Tools, closing, small ... ..	9	18
3	Tools, closing, small ... ..	2	8
4	Hammer, sledge ... ..	1	4

(b) Method of laying panels (*see* Plate 34).

- (i) Parties "A" and "B" lay panels A.1 and B.1 respectively, with the ends of the projecting longitudinal bars exactly on the transverse centre line, and leaving a gap of  $\frac{1}{16}$  inch between the adjacent ends of the transverse (top) bars of the two panels.
- (ii) Connect panel A.1 to B.1 by placing and fixing large joint covers over the abutting ends of the panel. The remaining joint covers may be fixed later.
- (iii) Lay panels A.2–A.5 and B.2–B.5 and connect together.
- (iv) Connect panels A.6 and B.6 to panels A.1 and B.1 by inserting the projections of the longitudinal bars exactly midway between the projections of the longitudinal bars of A.1 and B.1 and under the end transverse bars. This is effected by raising the leading transverse edges of panels A.6 and B.6 about 2 feet above the ground. The longitudinal projections along the trailing edge will then slip easily under the end transverse bars of panels A.1 and B.1.
- (v) Draw panels A.6 and B.6 into their correct final positions by two pairs of spacing tools, placed about 10 inches from either end of panels A.1 and B.1. To safeguard alignment great care must be taken not to move the latter panels.
- (vi) Place and fix two large joint covers on A.6 and B.6 in the corresponding position to those placed in A.1 and B.1.
- (vii) Lay and connect panels A.7–A.10 and B.7–B.10.
- (viii) Lay panels C.1, C.2, etc., and D.1, D.2, etc., by parties "C" and "D" respectively, working in the opposite direction to parties "A" and "B."

- (ix) The longitudinal joint between panels A.6 and B.6 is offset to the right of the longitudinal joint between panels A.1 and B.1 by an amount equal to  $\frac{1}{4}$  pitch of the bars. Care must be taken to ensure that panels A.11 and B.11 are inserted so that the longitudinal joints between them are offset to the left of the joint between panels A.6 and B.6, *i.e.*, it will lie on the same line as the joint between A.1 and B.1, thus preserving the longitudinal alignment of the runway.

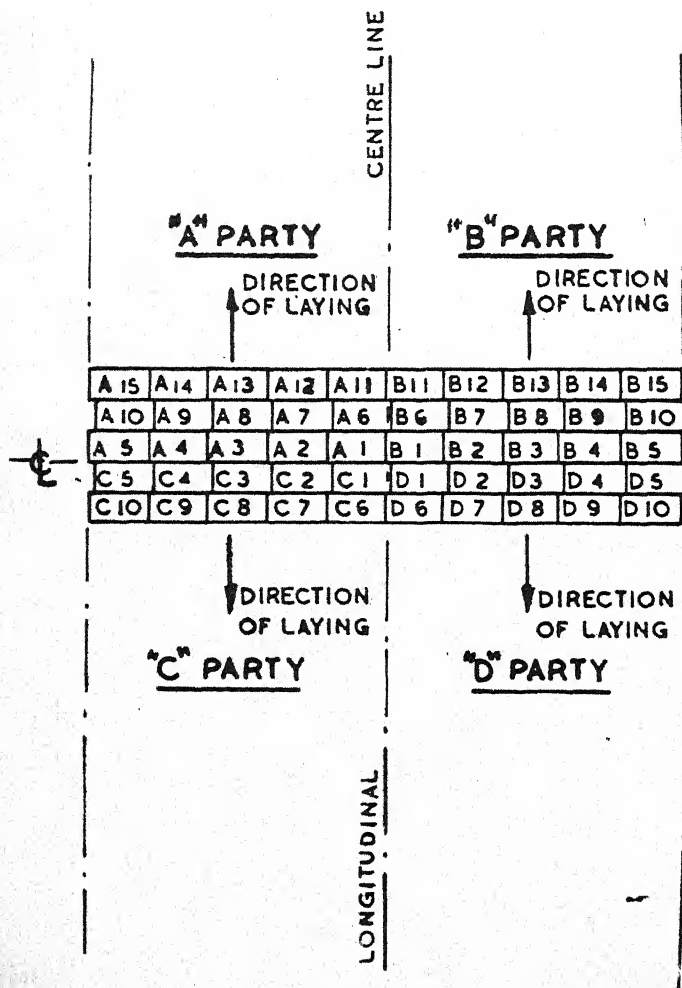


PLATE 34.—CHANNEL TRACK—METHOD OF LAYING PANELS

(x) In a runway 10 panels wide there are nine longitudinal joints. One man fixes all joint covers along one longitudinal row of joints, working outwards from the transverse centre line towards both ends of the runway.

(xi) Insert and fix spacing clips along the transverse panel joints. Clips are provided as follows :—

*Touch down areas* (end 300 yards of runway—2 per panel.

*Elsewhere*—1 every alternate panel.

(xii) Bend the edge of the end panel into the trenches by running the wheels of a loaded 3-ton lorry along the track. Picket down and back fill the trench with suitable material, and consolidate. An alternative method obviating damage to the panels and to prevent tyre damage to aircraft crossing the edges is to picket the track and then form a berm of sand or turf along the track edge, allowing 1 cubic yard of fill per 15 linear yards of runway edge.

(xiii) A picket should be driven in the outer edge of each external panel. In very soft ground the number of pickets per panel may be increased.

(xiv) Ends of runways are treated by trenching as in (xii) above.

(c) *Laying in echelon*

(i) A speedier method of laying using 20 laying parties is shown in Plate 35. For this purpose panels are provided with one end of the external longitudinal bars cut off from diagonally opposite corners.

(ii) The first panel must be laid on the left hand edge of the runway.

(iii) Lay panels A.1—J.1 first, followed by panels A.2 and A.3. Panel B.2 is then laid. When panel A.4 is laid panels B.3 and C.2 can be laid, and so on.

(iv) The outer row of panels in Row A must be laid accurately to line, and the lines set out truly at right angles to the transverse centre line.

## 7. Maintenance

(a) Damage, in the form of loose or deformed top bars, may result from traffic action. To obviate tyre damage, panels should be replaced, where the ends of the top bars have become loose.

Failure of individual bars in a panel, though not serious, calls for constant supervision to prevent further damage.

(b) Runways require frequent inspection for loose or damaged clips.

(c) Edges of runways, if protected by the berm method, must be inspected daily and displaced material made good. Neglect to do so may cause serious damage to aircraft running off the runway.

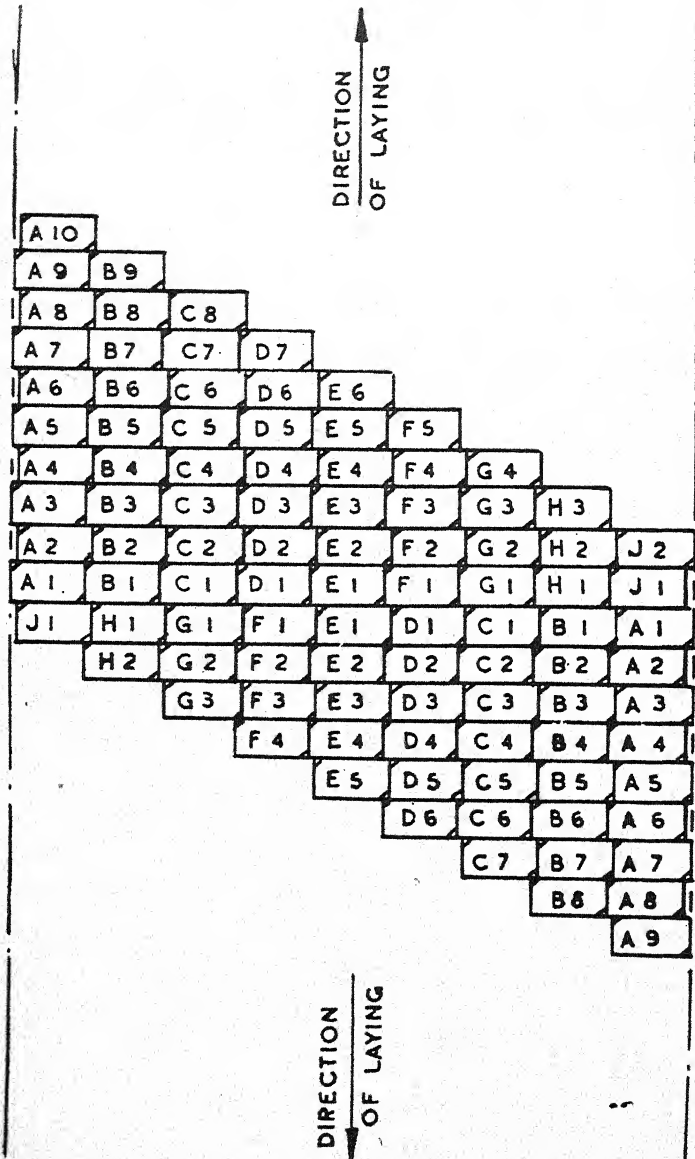


PLATE 35.—CHANNEL TRACK—LAYING OF PANELS  
IN ECHELON

Table IX.—Channel Track.—Stores required for Standard Runway\*

Serial No.	Description	Number required	Number per bundle	Number of bundles	Spares	Total number of bundles	Weight of bundles lb.	Total weight in long tons
1	Panels ... ..	15,836	10	1,584	156	1,740	1,916	1,485
2	Joint covers, large ... ..	150,216	55 } 10 }	2,732	268	3,000	48	64.3
3	Joint covers, small ... ..	27,312						
4	Spacing clips ... ..	15,836	56	283	27	310	48	6.56
5	Kit of tools† ... ..	30	—	30	2	32	97	1.39

\*1. One runway strip 99 ft. wide by 6,000 ft. long.

One taxi strip 55 ft. wide by 6,000 ft. long.

Four connecting lanes between taxi strip and runway, each 48.75 ft. wide by 100 ft. long

†2. Kit of tools comprises:—

2 closing tools, large.

2 closing tools, small.

1 opening tool.

2 panel spacing tools.

2 rectifying tools.

1 box container.

## SECTION 80.—A.R.C.

1. Practice closely comparable to that adopted for square mesh has developed in the Southern Pacific, using A.R.C. (3 inches by 3 inches by 3 gauge) mesh panels, 10 feet by 6 feet and weighing 84 lb. per sheet. Two types of clips are used, channel clips, weighing 0.38 lb., and strap clips, weighing 0.28 lb. Tool-channel clip is supplied for bending the tongue of the channel clip.

2. Staples, 24 inches long, weighing 1.5 lb. each, are used with every panel to hold the mat firmly to the ground, a condition of great importance with all types of light steel runway.

Eight staples are allowed per panel. It is found desirable, at every fourth or fifth row, to pull the panels taut by use of a truck or by levering with a crowbar, and to peg the mesh in this tightened condition until it has conformed thoroughly to local irregularities of surface. Ultimately, the majority of the staples are removed. Staples left in require close maintenance as they soon work out of the ground with traffic.

The mesh at the ends and edges of the runway is buried to a depth of 18 inches to prevent lifting and damage to tyres.

3. Factor of supply being favourable, it is common practice to lay an under-carpet of "fibreen" to prevent mud from coming through the mesh, or to keep down dust and grit. Under certain climatic conditions, the under-carpet also serves a good purpose in retarding the evaporation of moisture giving stability to the surface soil. Laid with a 4-inch overlap, the "fibreen" will contribute beneficially to a quick run-off under heavy rain.

## SECTION 81.—MISCELLANEOUS TYPES OF STEEL MATS

1. Although Heavy Bar and Rod, Irving Grid, and Army Track may not be used to any extent in future, brief references are made to their form and behaviour for general guidance. Practical experience gained with one type of mat throws light upon the characteristics of another.

2. **Heavy bar and rod.**—Weighing 3.9 lb. per square foot of coverage against 5.3 lb. for P.S.P., has not been widely employed, but has served a good intermediate service between P.S.P. and the light types of steel mat. Panels, 3 feet by 12 feet, are easily handled by two men and can be carried on a small truck without excessive overhang. The panel is made of mild steel; bars are  $\frac{3}{16}$  inch by 1 inch, and rods  $\frac{3}{8}$  inch diameter. Rigid connectors are commonly used. These are bands which encircle the outside bar of one panel and slide over the tip of a special connector on the adjacent panel, and are fixed by a crimping tool.

The standard method of laying is by using the runway centre line as a base. As soon as a two-panel distance is gained, additional rows in echelon can be laid in each quadrant. Each placing crew and each laying crew consists of four men. Panels and joints are staggered, joints being opposite the middle of the adjacent panel.

Experience has shown that bar and rod does not check evaporation of excess moisture in sub-grade or base course, but it does tend to

retard run-off and calls for a maximum permissible transverse gradient. This type must be laid with the long axis in the direction of the traffic. It must be well bedded into the soil or base course to prevent edge and end curve under heavy traffic. Strength can also be gained by filling the mat with impervious material.

Anchoring at the ends and edges is desirable as for P.S.P. If laid with the greater dimension of mesh longitudinally, anchors will be placed at every joint; if transversely, at intervals of not more than 6 feet.

**3. Light bar and rod.**—A light form of bar and rod, of the same material and general design as the heavy type, has been manufactured in large quantities, but has been supplanted in service by more robust types of steel mat. The panels are 12 feet by 3 feet, with bars  $\frac{1}{2}$  inch by  $\frac{3}{4}$  inch and rods  $\frac{1}{2}$  inch in diameter. Weight of panel is equivalent to 1.9 lb. per square foot of coverage.

**4. Irving Grid.**—This type is the heaviest made, with a weight of 5.6 lb. per square foot of coverage, and is less liable to deformation at the edges than P.S.P. or bar and rod. Results of service have been good but P.S.P. has superseded this type for general service, largely for reasons of supply.

Panels are 12 $\frac{1}{2}$  feet long by 22.3 inches wide, made of  $\frac{3}{16}$ -inch by 1-inch mild steel bars, and weigh 130 lb. each. Connectors are bands of a rigid type, as for heavy bar and rod, and are apt to be a source of trouble on a yielding sub-grade.

Laying drill is the same as for bar and rod.

Bent panels can be flattened separately by laying on the ground, convex side up, and running a truck over them.

**5. Sommerfeld track.**—This type of track has been used extensively in England, for fighter runways, taxi-tracks and hardstandings, upon turfed soil. Few opportunities have arisen for its successful application to operational conditions abroad, especially where marked seasonal changes of climate are characteristic. Commonly, soil conditions in a dry season are too favourable to necessitate its use. In a wet season soil conditions are too adverse to benefit. Sommerfeld track, with or without an under-carpet, has nevertheless an intermediate range of utility in runway construction of considerable importance. It will protect a grass landing ground during periods of rain, and checks the break-up by rutting of a sand or gravel surface of poor stability. Over an under-carpet of matting it has been used successfully in alleviating runway dust in an arid country, and can be employed effectively upon auxiliary services around an airfield.

To ensure good results when laying, effective transverse stretching is of special importance.

(a) *Component parts of the track comprise :—*

- (i) Stiffened netting of 3-inch or 2-inch mesh galvanized wire of 12-13 S.W.G. reinforced by  $\frac{3}{8}$ -inch diameter mild steel rods at approximately 8-inches centres. The ends of each rod are looped and welded for treating with linking bars. Rolls are 75 feet long and 10 feet 7 $\frac{1}{2}$  inches wide, weighing 900 lb.

## SECTION 83.—PREFABRICATED BITUMINOUS SURFACING

1. **Salient features.**—The small weight of P.B.S. is one of its outstanding merits. In a double-layer runway, it weighs appreciably less than any of the steel landing mats previously described.

Steel tracks of the square mesh or Sommerfeld types provide little protection against the effects of dust or heavy rain, whilst P.B.S. requires a better surface for efficient application, is more difficult to lay in bad weather, and delays indefinitely the drying out of excess moisture in the soil at the time of laying.

## 2. Details of mat

(a) P.B.S. Mark 1 is made up of :—

	<i>Weight per sq. yd.</i>
Hessian ... ..	8.7 oz. minimum
Bituminous saturant (60—80 pen)	6.3 oz. average
Coating of relatively hard, high softening point bitumen ...	36.0 oz. average
Dusting powder ... ..	2.5 oz.

53.5 oz. average

(Minimum weight 45.5 oz., maximum 58.0 oz.)

Weight of former equals 0.225 lb.

Total weight, double laid, per square yard of runway, 7.2 lb.

(b) Rolls, equal to 80 yards long by 1.11 yards wide, weigh 320 lb. and are of 1-foot 5-inch diameter in the roll. Twenty rolls are carried in a 3-ton lorry, representing 58 lorry loads per 1,000 yards of a 50-yard wide runway.

In order to prevent sticking of the sheets while rolled they are dusted with slate flour, chalk dust, stearated calcium carbonate or other water-repellent substance.

Cracks can be sealed satisfactorily by surface treatment with oil and petrol solvent.

Bitumens used conform to specifications suitable for climatic conditions in the countries to be served or likely to be met in transit.

(c) In India, a heavier type of bituminized hessian is used, known as P.B.S.6. This comprises :—

Fabric ... ..	22 oz. per sq. yd.
Saturant (90/100 pen) ... ..	22 oz. " "
Coating on one side ... ..	15 oz. " "
Coating on other side ... ..	37 oz. " "
Total per square yard ... ..	6 lb.

This thicker type is laid in a single or double layer, according to soil characteristics.

The Indian rolls are made up in either 50-yard or 35-yard lengths of 32 inches width. The rolls are 22 inches and 16 inches diameter respectively, with a former of 3-inch bamboo projecting  $5\frac{1}{2}$  inches at each end. The weight of the rolls is 280 lb. for 50-yard length and 194 lb. for 35-yard length.

### 3. Laying procedure

- (a) The formation must be well graded and compacted to allow efficient adhesion of the mat to the soil, and all stones removed or rolled well in.
- (b) The strips are laid longitudinally from each edge towards the centre, with a 55 per cent. overlap. Double thickness is provided throughout.

Rolls are marked with a 3-inch red centre line, which is laid uppermost and is just covered by the overlying layer of P.B.S.

The first strips must be aligned with extreme care, being the base lines for control of the correct laying of the whole task. A closure strip is laid over the joint along the centre line of the runway.

- (c) The strips are cemented together by softening the bitumen coating with a solvent fluid such as petrol, diesel oil, kerosene or bitumen cut-back or combinations of these products. This solvent fluid may also improve, in small degree, the bond between the hessian and the soil. Normally this solvent will vary from 70 per cent. petrol and 30 per cent. diesel to 50 per cent. of each, according to climatic conditions.

Strips can also be joined by the use of petrol-, paraffin- or diesel-burning portable torches, which liquefy the bitumen coating of the hessian. Torch work is slow and needs considerable skill, but it can be adopted in light rain, and has the advantage of ensuring immediate and effective adhesion.

- (d) Pressure applied by a pneumatic roller, V-broom or sandbag finisher will ensure a good bonding of lap joints between overlapping strips.
- (e) P.B.S. may be laid by hand or by mechanical methods. An outline of practice only will be given below.

4. Hand methods may be advantageous, although slower, under certain operational conditions, in countries of abundant labour supply, for small tasks and for maintenance. The solvent is then usually applied by means of mops and brooms or as a spray.

5. Laying by machine involves the use of a P.B.S. Laying Machine ("Lick Roller" or "Stamp-licker") of towed or stationary type. Its functions are :—

- (a) To apply the solvent to the under-side of the P.B.S., and
- (b) To lay the material evenly upon the compacted surface.

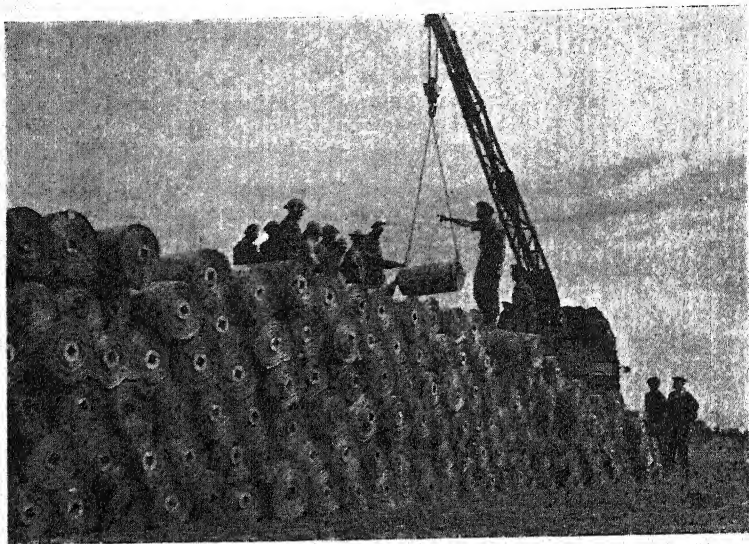


PLATE 37.—P.B.S.—STOCKPILE ON AIRFIELD



PLATE 38.—"STAMP LICKER"—LAYING NEW ROLL OF PBS

When at work upon a new runway, these machines travel in echelon in an anti-clockwise direction, three normally working along each edge simultaneously. The speed of the machines should not exceed 4 m.p.h., to ensure even treatment and to avoid overstrain of mat, but it should not drop below  $2\frac{1}{2}$  m.p.h.

The machines are towed very steadily by three-ton lorries, fitted with roll racks. There will be three lorries to each laying machine—one operating, one loaded, and one loading. Each lorry carries 1,200 yards run of mat.

(a) *Working procedure*

- (i) Two men of each surfacing squad follow behind their plant, brooming down, sealing joints, and removing creases. Pneumatic rollers should be used continuously until the field is opened for service.
- (ii) At the ends and edges of the runway, 18 inches of the outer mat are buried in an anchor trench to check water percolation from outside. The mat can also be carried to depth, as locally required, to wall off shallow subsoil water. This work should not be done until rolling is finished.
- (iii) To obtain a non-skid surface, the finished surface is treated with a fine spray of mixed diesel oil and petrol, applied with a pneumatic paint spray-gun at the rate of 1 gallon per 60 square yards, immediately covered with about 3 lb. of wet or dry sand to the square yard, and rolled. A party of 13 men with two trucks, one roller and one spray-gun will treat upwards of 1,000 square yards per hour.

An alternative is to spray the surface with a normal cut-back bitumen (M.C.3) at about  $\frac{1}{4}$  gallon per square yard, and blind with dry sand. Material over  $\frac{1}{4}$  inch should not be used for blinding.

With less efficient results, sand sprayed with a mixture of oil and petrol can be spread on the mat at the rate of 2 to 4 lb. per square yard and rolled in with a pneumatic tyred, or light flat roller after spreading. Sand failing to adhere is swept off in a few days.

(b) *Materials*.—Requirements for a typical runway, 1,200 yards by 50 yards, with use of surfacing machines are :—

Number of rolls—1,400, weighing approximately 200 tons.

- Solvents : petrol and diesel oil, 30 tons.
- 6 surfacing machines and 18 three-ton lorries.
- 2 five-cwt. trucks.
- 4 V-broom or sandbag drag finishers.
- 2 pneumatic rollers.
- 50 brooms, bass.

(c) *Labour organization* ("Lick Roller" method)

	N.C.Os.	Men
Survey party, laying out side and checking alignments ... ..	1	4
Loading party, servicing P.B.S. tow-trucks with material ... ..	2	24
Laying parties (6 machines). Servicing machines, driving, sweeping and aligning	6	66
Solvent mixing party (1 each end) ...	2	10
Joint sealing party ... ..	2	10
General supervision ... ..	3	
	16	114

A 1,200-yard by 50-yard runway should be completed in 14 to 16 hours; 200 square feet per man-hour can be taken as a rough standard, subject to considerable variation for weather conditions.

On an airfield in N.W. Europe 5,000 feet by 120 feet runway, together with marshalling areas and 5,300 feet of taxi-tracks 35 feet wide—total area 107,433 square yards—was laid in five days of 12 hours each, using six laying machines. This represented 16.5 square yards per man-hour.

For off-loading and laying out stores at each end of runway, 100 men are required before laying starts. Stock piles should have a maximum height of six rolls. (*See Plate 37*).

6. **Secondary applications.**—The laying of P.B.S. has been proposed for the first stage in the construction of a permanent airfield surfacing, protecting a sub-grade against softening by percolation through a stone or sand pavement, or holding the strength of the sub-grade to enable heavier construction to proceed during spells of bad weather.

There is also scope for experimental development of a "mattress" of stable soil, of variable thickness, compacted upon a base of P.B.S. and covered by a second carpet as a wearing surface. By this means, thickness might be obtained to spread the load imposed upon a sub-grade which is found to be of treacherous character, either because of the danger of softening through rise of subsoil water, or because of its inherent weakness.

Where there is occasion to strengthen the P.B.S., owing to abnormal wear or soil weakness, square mesh track may be beneficially superimposed. Care must be taken to prevent damage to the hessian by careful fixing of clips. If Sommerfeld track is superimposed, it is liable to puncture the fabric.

7. It is important that P.B.S. should be laid in close contact, throughout, with a well-graded surface. Wrinkles are apt to result from inaccurate grading, uneven tension when laying, errors in alignment, and from air pockets trapped between sheets.

8. Laying in bad weather is a difficult task. Rain is detrimental, although the dusting powder has water repellent properties. In strong cross-winds, weights may have to be placed on the strips as they are laid—half-filled sandbags, petrol cans, bricks and stones will serve the purpose—until adhesion between strips is effective. Alternatively, two layers may be held together by applying a hot asphalt iron to the P.B.S. at intervals along the joint. The action of the solvent is to soften the bitumen and make it tacky. Good adhesion is not obtained until the solvent has partially evaporated, a matter of some hours.

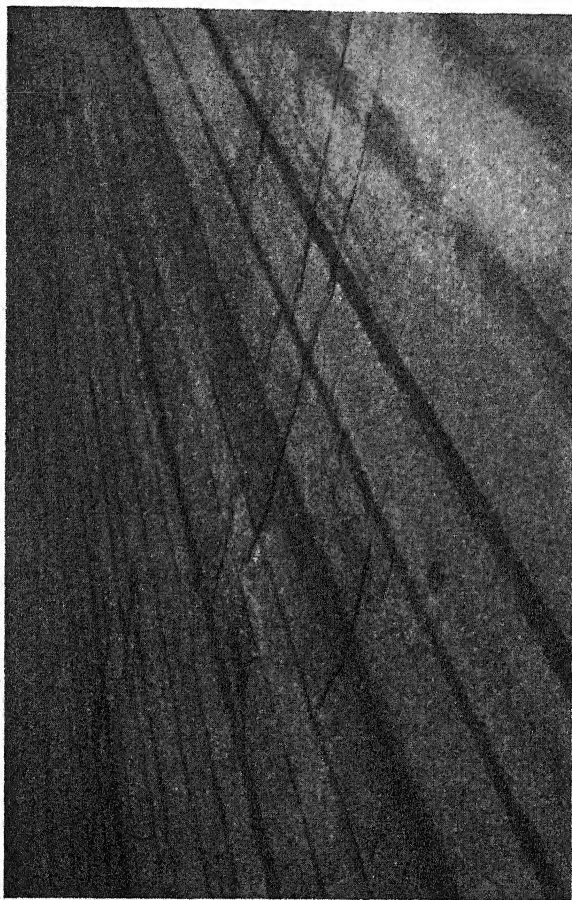


PLATE 39.—P.B.S. TRANSVERSE WRINKLES PRODUCED BY TRAFFIC



PLATE 42.—RUTTING ON PERIMETER TRACK DUE TO P.B.S. BEING LAID ON SOFT GROUND. (NOTE ABSENCE OF CRACKING AND TEARING)

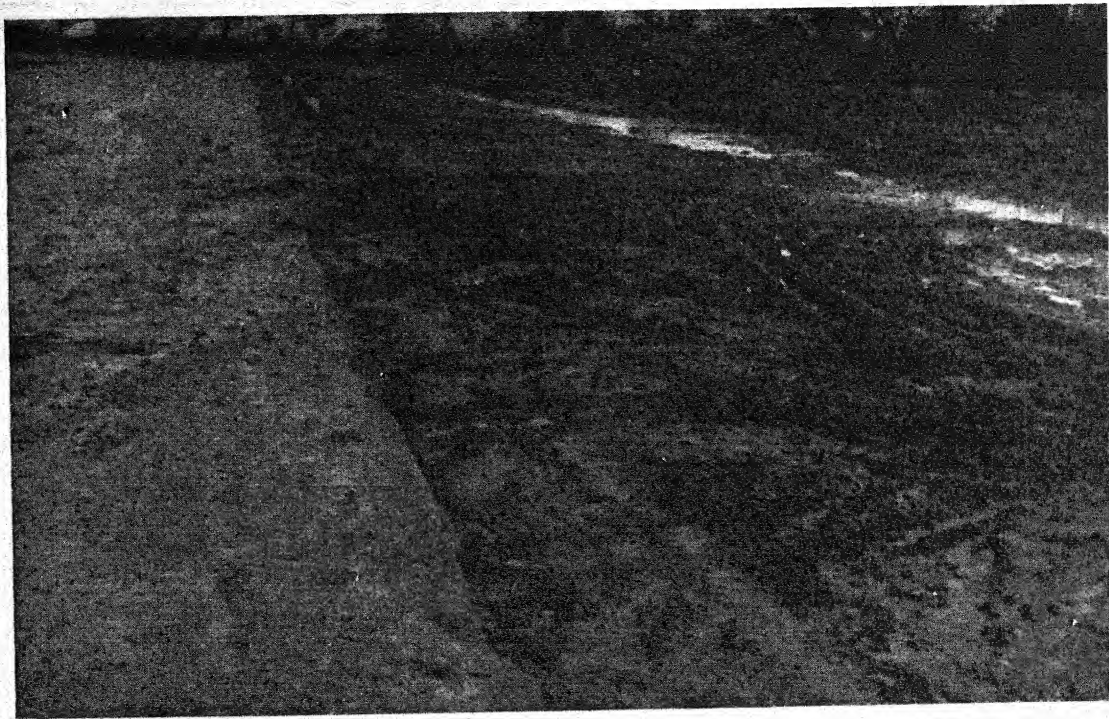


PLATE 43.—GROUND CONDITIONS AT EDGE OF PERIMETER TRACK.  
(NOTE ABSENCE OF RUTTING ON P.B.S.)

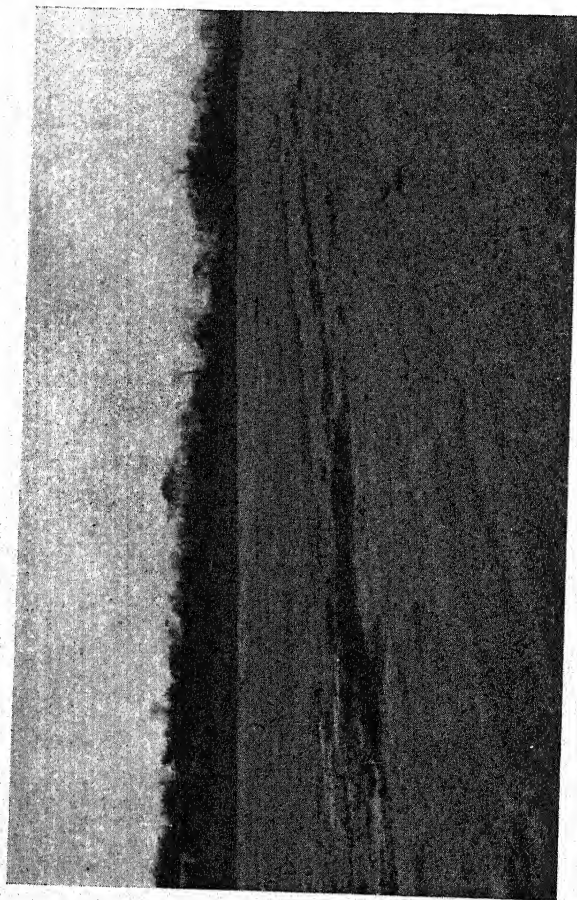


PLATE 44.—CONDITION OF P.B.S. FOUR MONTHS AFTER LAYING  
(NOTE SMALL FAILED AREAS DUE TO LACK OF MAINTENANCE)

## CHAPTER 12

## BITUMEN, TAR AND CEMENT

## SECTION 84.—GENERAL

1. Detailed methods of construction in cement or bituminous materials are discussed in Military Engineering, Volume V, Part I, "Roads." References in this manual will be chiefly confined to the description of specifications actually adopted for airfield construction in operational areas. Bitumen and cement are generally both available in theatres of war, but the bias will be in favour of bituminous runways for three reasons :—

- (a) When shortages arise, cement can be made to replace bitumen or tar in surfacing work, but bitumen cannot replace cement in its most important military applications.
- (b) Flexible types of runway construction are favoured because of the greater scope for variation in type and quality of aggregate, and for hasty work where durability is unimportant.
- (c) Runway repairs, consequent upon enemy action or upon any deterioration associated with hasty work and speculative factors of safety, can be effected more easily.

2. These factors have no bearing upon the relative inherent merits of rigid and flexible pavements, where there is full freedom of choice, and where engineering and economic factors alone prevail.

3. Military engineers will require to be familiar with both types of pavement and their particular adaptabilities to varying circumstances.

## SECTION 85.—BITUMINOUS MATERIALS

1. It is desirable that the definitions of common bituminous materials, in British and American equivalents, should be put on record, not only to prevent administrative confusion but for the better understanding of technical reports and literature exchanged between Allied airfield engineers.

2. The product derived from the distillation of petroleum or from natural asphalt deposits is called "bitumen" (Br.) or "asphalt" (U.S.A.). "Tars" are the products of coking bituminous coal (Br. and U.S.A.).

In U.S.A., "bitumen" covers both products, "asphalt" (U.S.A.) and tar.

In Britain, "asphalt" is a natural or mechanical mixture, in which bitumen is associated with inert mineral matter.

3. Bitumen, at normal temperatures, is too hard (viscous) to mix or spray. For construction purposes, it must be made temporarily fluid and subsequently resume its stability.

Apart from heating alone, which results in temporary fluidity, bitumen is given the required consistency by blending with petroleum distillates or by emulsification.

Bitumen is blended (cut-back) with different solvents. When naphtha is used, the products are called rapid curing or R.C. cut-backs; when kerosene, medium curing or M.C. cut-backs, the solvent evaporating more slowly than in the R.C. grades.

There is a third grade of bitumen product known as slow curing or S.C. (U.S.A.), which represent low volatile oils left or blended with bitumen residues near the end of the refining process. These have not been made available for airfield work.

4. Coal tar is distilled until its consistency is suitable for surfacing work, or is cut back with distillate oils to the required grade.

5. Emulsions consist of a very fine dispersion of bituminous material in water, and held in suspension with the aid of an emulsifying agent, such as soap.

**Table X.—Road Tars. Correlation of American and British grades**

AMERICAN GRADES		BRITISH GRADES		USE
Type	Application temperatures °F.	Viscosity	Application temperatures °F.	
R.T. 1 & 2	60-125	10-20 secs. at 30°C.	2 00-225	As a tack-coat, or initial surface dressing of water-bound or earth-road, in winter.
R.T. 3	80-150	20-30 secs. at 30°C.	200-220	As above, but for use in summer.
R.T. 4 & 5 6 & 7	80-150 150-225	No British	equivalents	These are cold tars which are not used in Britain.
R.T. 8	150-225	20-40 secs. at 30°C.	200-220	General surface dressing and base coats in winter.
R.T. 9 & 10	175-250	80-120 secs. at 30°C.	200-220	General surface dressing and base coats in summer.
R.T. 11	175-250	30-50 secs. at 30°C.	200-220	Grouted Macadam in winter.
R.T. 12	175-250	80-120 secs. at 30°C.	200-220	Grouted Macadam in summer.
R.T.C.B. 5 & 6	60-120	No British	equivalents	

These tars are all classified as type "A", of rapid setting properties. Type "C", very slow setting, and type "B", intermediate, are rarely used.

**Table XI.—Bitumens—American and British types**

American description Asphalt				British description Bitumen	
40/50 Penetration	...	...	...	...	} Nil 60/80 Penetration
50/60	...	...	...	...	
60/70	...	...	...	...	
70/80	...	...	...	...	
85/100	...	...	...	...	80/100
100/120	...	...	...	...	
120/150	...	...	...	...	120/140
150/200	...	...	...	...	180/220

**Table XII.—Bitumens and Cutbacks—Correlation of American and British grades**

AMERICAN GRADES	BRITISH GRADES	USE
Cutback asphalt (Naphtha). Rapid curing. R.C.O.—R.C. 5.	Not normally manu- factured in Britain, but R.C. 3 is being produced to the American specifica- tion.	Surface treatments. Plant mix and mix-in- place. Stone coating (Macadam).
Cutback asphalt (Kerosene). Medium curing M.C.O.— M.C. 5.	Pool cutback bitumens Nos. 1, 1A, 2 and 3. (The viscosities of which are compar- able with M.C. 4— M.C. 5). F. 70 (Middle East) is comparable with M.C. 4.	Grouting. Surfaces treatments. Plant mix and mix-in- place. Stone coating (Macadam).
Asphaltic road oils.	No British equivalent.	Grouting. Hot laid plant-mix.
Slow curing. S.C.O.—S.C. 6.		
No American equivalent.	"S.R.O."—special road oil.	Used for coating wet sand.

**Table XIII.—Asphalt emulsions**

AMERICAN GRADES		BRITISH GRADES		USE
Type	Application temperature	Type	Application temperature	
R.S. 1 (rapid setting).	60–120°F.	Labile B.S.S. 434/35 (unstable).	Atmos- pheric, not below 50°C.	Penetration and surface treatments.
M.S. 1— M.S. 3. (medium or normal setting).	60–120°F.	Semi-stable (no specifi- cation; proprietary brands only).	Atmos- pheric.	Mixed in place and plant mixes, with coarse aggregate.
S.S. 1—S.S. 2. (slow setting).	50–120°F.	Stable (no specifi- cation; proprietary brands only).	Atmos- pheric	Mixed in place and plant mixes, with fine aggregate.

6. In operational areas, every effort will be made to reduce the number of different types of bituminous material employed to an absolute minimum. Even with a wide range of climatic conditions, the following are the only grades likely to be made available, and not more than four of these are likely to be supplied in any particular theatre.

*Cutbacks*

R.C.3.

M.C.3. (F.70)

*Bitumen*

60/80 penetration.

80/100 penetration.

*Tars*

40 viscosity (winter).

100 viscosity (summer).

*Emulsions*

Rapid setting.

The above list, in addition to R.C.2 and M.C.2, covers all grades commonly referred to in technical reports upon airfield construction abroad.

## CHAPTER 13

## BITUMEN AND TAR SPECIFICATIONS

## SECTION 86.—SAND-BITUMEN MIX.—DRY

1. The wide adoption of sand-bitumen mix practice has been due to the long established suitability of dry methods in hot arid countries, and to the recent successful expansion of the wet-sand process in Britain. Abundance of sand *in situ* and a shortage of stone, crusher plant, and other facilities for heavier construction, were factors considered, at one time, essential for competitive efficiency. Applications in war have been gradually widening. Sand-mix runways have been made, in preference to stone, even where transport distances for sand have been considerable. Tonnages handled are small; speed of construction is high; the carpet can be laid in a single operation; and—of primary importance—it protects the sub-soil from the effect of heavy rains which might be disastrous to any other type of thin pavement, without similar waterproofing qualities.

Methods of construction and binder details are discussed in Military Engineering, Volume V, Part I—"Roads." Only features of special significance in operational airfield construction will be covered in this chapter. With the lower intensity of traffic, airfield carpets can be thinner than road surfaces, but impermeability is commonly a more urgent quality.

2. **Middle East practice.**—The formation for a sand-bitumen mix runway must be prepared and compacted with particular care. Irregularities in the formation are apt to be reproduced in the final surface. Soft patches must be dug out, refilled with gravel or crushed stone, and consolidated. At all stages, mixing and spreading must be controlled with the utmost thoroughness and skill. Reliance upon the toughness and impermeability of a thin carpet leaves no margin for faulty work. The total thickness provides little "spread" to the load imposed upon the natural or stabilized soil below it.

When the tactical situation is semi-static, the advantages of sand-bitumen mix and pierced steel plank have frequently called for practical comparison. Upon soil with a high clay content, of adequate bearing strength at optimum or lower moisture content but soft and treacherous after rain, P.S.P. will demand a considerable base course to stifle the mud and spread the load, representing a heavier tonnage than that of the sand in a bitumen sand-mix carpet. The steel mat represents a heavier import tonnage than the corresponding bitumen and mixing plant. The base course for the mat would make the heavier call on mechanical equipment; the sand-mix carpet, the heavier call on labour. On speed of construction, there would be little to choose.

**3. Sand aggregate.**—The ideal aggregate consists of grains varying from coarse to fine, which can all be individually coated by bituminous binder in a mixing machine, without excessive consumption of bitumen.

Omitting some small fraction of gravel and coarse sand, the best gradings are :—

Minus 10 mesh, plus 40...	...	...	...	10-40 per cent.
Minus 40 mesh, plus 80	...	...	...	22-45 per cent.
Minus 80 mesh, plus 200	...	...	...	12-30 per cent.
Minus 200 mesh	...	...	...	10-20 per cent.

Satisfactory mixes have been recorded with 25 to 30 per cent. passing 200 mesh, whilst less than 8 per cent. has occasionally shown failure. Too much filler is to be avoided because :—

- (a) More binder is necessary to coat the particles.
- (b) The fines are apt to coagulate into lumps.
- (c) Mixing and spreading operations become longer and more difficult.

**4. Mixing and spreading.**—An airfield presents special opportunities for the use of big mechanical mixers, spreaders, and finishers, but in operational areas small mixing plants and hand labour have obvious advantages. A well-balanced organization, in spite of irregularity of supplies, is more easily maintained. Native labour is more readily employed.

Upon an airfield, of moderate priority, work will be organized normally on a basis of 150,000 square yards per month, with a period of maximum output producing a runway of 2,000 yards by 50 yards in little over two weeks.

Paddle mixer output must not be forced ; the accurate gauging of aggregate and binder is of first importance. Measurements should be made foolproof. Too much binder is often used to facilitate mixing, which should take an average of 1 minute, unless the weather is cold or aggregate damp. Too much bitumen produces a soft carpet, which will not set ; too little, a dry brittle carpet, which is liable to crumble under traffic.

Whatever the time allowed, the temperature of the mix, or the grading of the sand, a moisture content of 5 per cent. is excessive for efficiency without the use of driers or the addition of lime, or cement to assist the adhesion of the bitumen to the sand.

Transport of the mix from the mixer to the spreading site may be effected by native baskets, decauville skips, lorries, wheelbarrows, or pneumatic-tired barrows ; the last-named are the most satisfactory for normal carries up to 100 yards.

The mix is dumped on to metal or wooden sheets close to the spreading site and thrown lightly into position by shovel or fork. The carpet is then spread by rakes to the required thickness, which is controlled by wooden or steel side-guides, wooden blocks or other means. The spread should be as light and even as possible, all compaction at this stage being carefully avoided.

**5. Compaction.**—Initial compaction by hand-tamping should be carried out as soon as possible ; it is perhaps the most important factor in consolidation. Working with hand-labour, two or three tampers are employed to apply the first tamping and keep up with the laying. Another gang of men, standing shoulder to shoulder, follow up at 10 yards distance, giving the work a thorough tamping and advancing only

a few inches at a time. After adequate hand-tamping, even heavy rolling should not produce much more than  $\frac{1}{4}$  or  $\frac{3}{8}$  inch lowering of the surface.

Secondary compaction may be done by pneumatic rollers or by light solid rollers. Pneumatic rollers and vehicular traffic are beneficial in their kneading action, which pushes the particles into a closer and more permanent fit. Final compaction is carried out with solid rollers, any undulations being removed by cross and diagonal rolling. A guiding principle for rolling, in order to allow the runway to be fit for service as soon as possible after laying, is that it should be done as early as possible, with as heavy a roller as can be used without causing cracks or horizontal movement in the carpet. Vehicles should be encouraged to use the completed portion of the strip as much as possible, even if such traffic has to be prohibited during the warmer hours of the day.

**6. Data for typical airfield construction** in desert country, with minimum equipment, and native troops or labour. This represents a routine, economical task without extreme urgency, where labour is plentiful.

Sand-bitumen mix—4 inches uncompacted thickness.

Work, 10 hours per day, continuous.

Daily progress—5,250 square yards.

Paddle-mixers—enough to maintain seven in continuous operation under service conditions. Thirty batches per hour.

Bitumen, 1,000 tons per month, at 16 gallons per cubic yard of sand.

Sand at 106 lb. per cubic foot.

Labour.	Bitumen supply	...	20	
	Mixing and loading	...	200	
	Offload and spread	...	200	
	Formation	...	100	
	Kerbing	...	120	
			Total	...
			640	excluding technical control, supply of sand, and lorry drivers.
Transport.	Bitumen	...	...	11 lorry trips daily.
	Sand	...	...	189 lorry trips daily.
	Sand-mix	...	...	200 lorry trips daily.
	Kerbing stone	...	...	10 lorry trips daily.
			410	lorry trips daily.

Sand bitumen mix bulks one third and is finally compacted to original volume.

Lorries or equivalent decauville track, for transport of sand-mix, are not required when paddle-mixers are erected on site and move along the edges of the runway with the work.

With experienced military personnel, suitable sand within scraper distance, and adequate equipment, a labour force of 500 men would be required for the above progress, representing over 100 yards of runway per day.

In emergency, sand bitumen-mix runways have been constructed in the Middle East at a daily rate of 9,000–10,000 square yards over a considerable period, with records of 11,000–12,000 square yards, laid in a single day.

## SECTION 87.—SAND-BITUMEN MIX.—WET SAND

1. Sand, in a wet and cold condition, has been used with efficiency and economy, in the construction of many airfields in Britain. The use of sand driers or emulsion has been obviated by adding to the wet aggregate an alkaline substance, such as hydrated lime or cement, which assists adhesion of the tar or bitumen to the sand particles in the presence of water.

In the case of bitumen, but not of tar, better results are obtained by the further addition of a special reagent to the binder, either to improve initial coating or to prevent subsequent displacement of the binder from the aggregate by water. This reagent—iron oleate or other metal soap—is incorporated, at 2 per cent., in the binder as received from the oil company.

2. **Typical practice in Britain.**—Clean sand is selected, containing not more than 5 per cent. of clay or vegetable matter, provided moisture content is not in excess of 6 per cent. A fair percentage of gravel and coarse sand is desirable, for economy in binder, consumption of which varies from 4 to 7 per cent. according to the grain-size distribution. Hydrated lime, equal to 2 or 3 per cent. by weight of the aggregate, is added at the mixer.

3. **Mixing plant.** Two types of plant are used :—

- (a) Batch paddle mixers, commonly of 10 cubic feet capacity, driven by 14 h.p. diesel engine.

A complete unit equipment consists of eight mixers, eight 250-gallon boilers, twelve lorries and two finishing machines.

The average output of a mixer is 7 cubic yards per hour, giving approximately 500 square yards, 4 inches compacted thickness, per day of 10 hours.

Mixing is longer with the wet-sand process than the dry, and takes from one to three minutes, depending on the temperature of the material and grading of the sand.

The processed material is discharged into lorries or "Dobbin" barrows and transported to the site of laying.

- (b) Travelling mixers—types used in Britain : Barber-Greene and Pioneer. (Wood's road mixer also used abroad.)

To serve these machines, the sand is assembled into windrows by means of a motor grader or angledozer.

The cross-section is regulated for the thickness and width of carpet to be laid. Hydrated lime is laid in bags on the top of the windrow to give the 2 per cent. mixture, the bags being opened upon the approach of the mixing machine.

The mixed sand and lime is elevated to the hopper as the machine travels along the windrow, then passes through an adjustable gate, and is met by a jet of bitumen before entering the mixing mill. The binder flow is constant and the mix is controlled by opening and closing the gate which varies the rate of flow and aggregate. After mixing, the material is discharged at the rear of the machine, either into lorries or direct to a finishing machine by means of a belt conveyor.

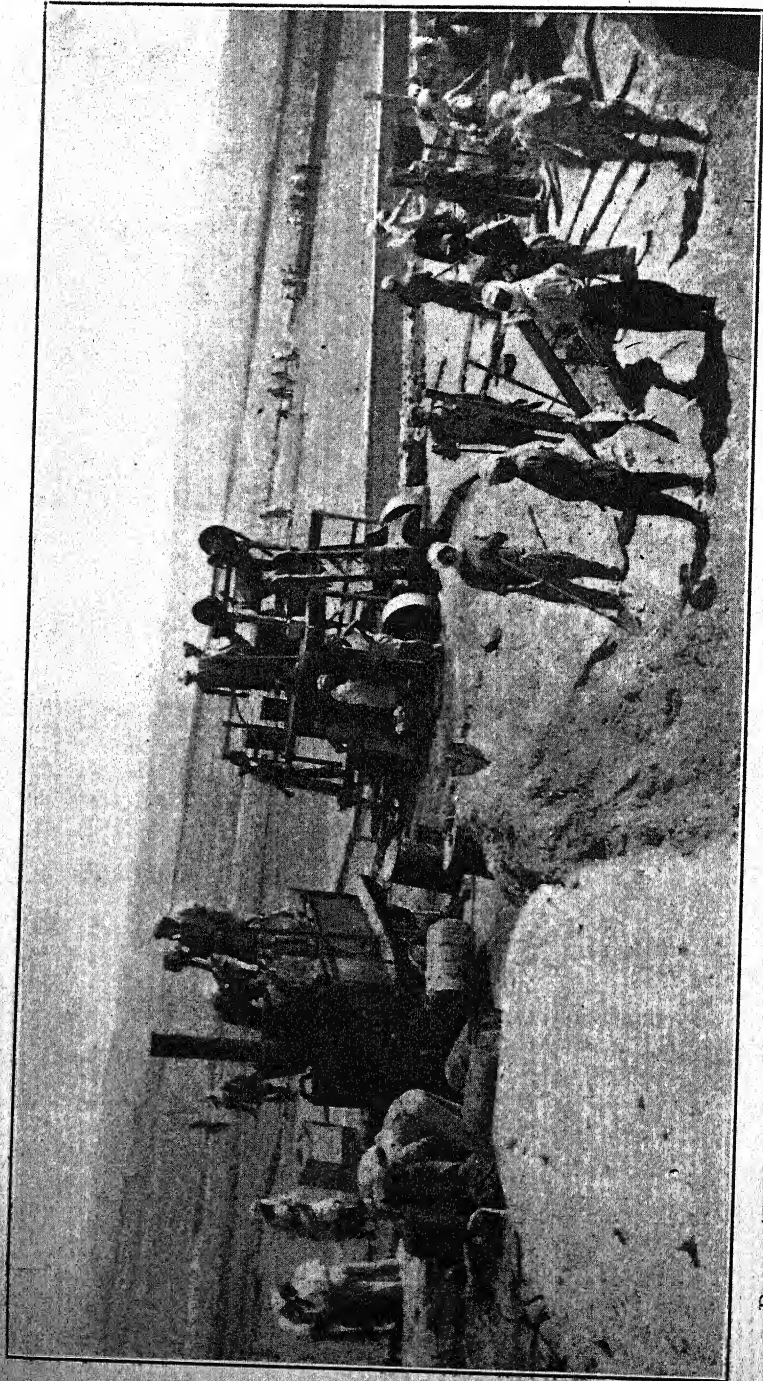


PLATE 45.—SAND-BITUMEN MIX—BOILER AND 10 CU. FT. MIXER ON MIDDLE EAST AIRFIELD

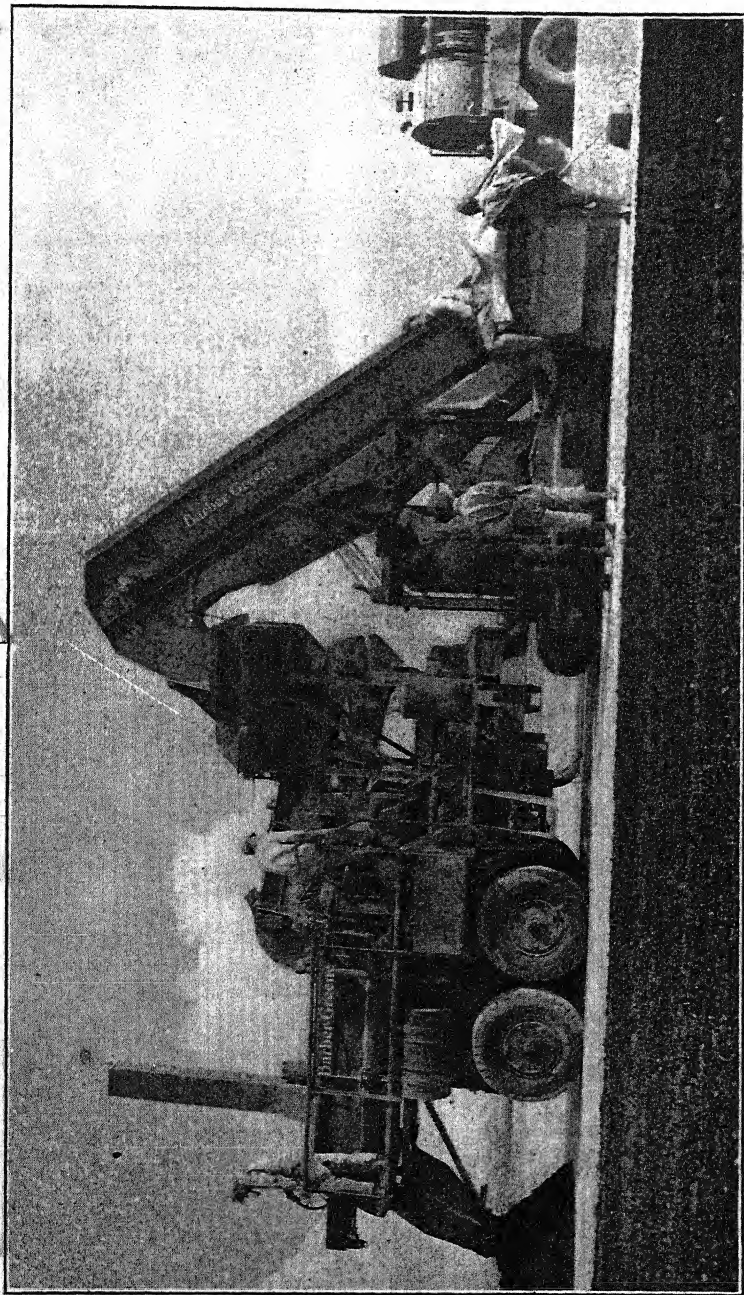


PLATE 46.—BARBER-GREENE TRAVELLING MIXER, SHOWING MIXED AND UNMIXED WINDROW

**4. Laying carpet.**—Laying can be done by finishing machine or by hand. The types of finishing machine in use are Barber-Greene, Jaeger and Adnam.

The mixed material, after being fed into a hopper by lorry, passes to a distributing screw and is then struck off to the desired level by a vibrating tamping board. If hand spreading is adopted, screed boards must be set and the material spread to the required level with heated rakes.

Initial rolling is carried out immediately after the mixed material is laid. A flat-plated tractor is used to avoid disturbing the fresh surface. This is followed within 24 hours by further rolling with a heavier type of caterpillar tractor. Final rolling is carried out a week or ten days after laying, with a 6-ton roller.

Work can proceed during spells of wet weather, without serious loss of efficiency. When much wet weather is anticipated, it is good practice to lay a rough 2-inch base course to keep the formation dry and firm, so that work on the final surface can proceed without interruption. In some cases, a double 3-inch layer of sand-mix will be laid, to ensure the efficiency of the upper.

It has been clearly demonstrated, in several regions, that given clean sand within a few miles of the site, the wet-sand process compares favourably with any alternative in speed, economy, and final efficiency of surface, for all types of aircraft.

**5. Details of specific airfield (Britain).**—The following particulars relate to a big airfield in N.E. England, constructed by the wet-sand process :—

Dimensions : Runway—3,000 yards by 250 yards.  
Dispersal bays and loops—50 feet by 1,500 feet.  
Total area : 833,000 square yards.

Soil : (a) Surface—arable land.

(b) Sub-soil—heavy undrained boulder-clay.

Base : 2 inches of ashes or slag dust as a blanket coat.  
4 inches of 3-inch slag, "as dug" or crusher run, blinded and consolidated.

Surface : 4 inches compacted sand-bitumen mix.

Sand aggregate : Coarse sand down to 100 mesh, with approximately 10 per cent. small stone.

Moisture content : 3–8 per cent.

Binder :  $4\frac{1}{2}$  per cent. bitumen, including the reagent, ("S.R.") or special road oil). 3 per cent. of hydrated lime.

Plant : Six 6 cubic yard scrapers (Le Tourneau).  
Sixteen 10 cubic feet paddle mixers and boilers.  
Three Barber-Greene spreaders.  
Thirty-three 3-ton tipping lorries.

Labour : Average of 200 men, working 10 hours per day.

Rolling : Immediately after laying roll with flat plated roller, followed in 24 hours by a 6-ton tandem roller. Lorry traffic was turned on to the surface three days after laying.

Progress was governed by speed of work on formation and base courses. Average progress on runway, 18,000 yards per week, with a record week of 42,000 square yards. The whole task took 10 months, of which 7 months were on surfacing, with 30 days lost through rain and snow.

With the layout employed, a surfacing rate of 40,000–50,000 yards a week could be maintained under favourable conditions, just as comparably, 50,000–60,000 yards a week is readily attainable, with the dry-sand process, in a hot and arid climate.

#### SECTION 88.—BITUMEN-STONE (GROUTED)

##### 1. Example of grouted stone airfield constructed in 1943 near Tunis

Task: Paved runway of 1,550 yards by 50 yards wide, with taxi-tracks, access roads and 100 hardstandings.

2. Owing to limited choice of area, the airfield was built on low-lying ground. The water-table in summer was at a depth of 3 feet and just below or at surface level in winter.

The soil was a mixture of clay and silt, treacherous when wet, but of adequate bearing strength in a dry state.

The specification provided a 4-inch thickness of graded stone (4 inches— $\frac{3}{4}$  inch), with a  $1\frac{1}{2}$ -inch wearing course, sprayed with bitumen at 1 gallon per square yard.

Cross-fall for the paved area of the landing lane was 1 in 75, and the fall from the haunches of the paved area to the edge of the landing lane, at 1 in 82, was designed to balance cut and fill.

##### 3. Troops employed were :—

One Airfield Construction Group, H.Q.

One Artizan Works Company, R.E.

One Mechanical Equipment Section, R.E.

One Quarrying Company, R.E.

Three companies Pioneer Corps.

Average working numbers from these units totalled 900. Later two companies Pioneer Corps were added and for the final four weeks, number of men at work was 1,300, excluding administration and maintenance of plant.

##### 4. Plant available :—

<i>Description</i>	<i>First 8 weeks</i>	<i>Final 4 weeks</i>
Tractors, Class I ... ..	7	10
Tractors, Class II ... ..	4	3
Tractors, Class IV ... ..	2	7
Scrapers, 12-yard ... ..	6	8
Scrapers, 8-yard ... ..	4	4
Scrapers, 4-yard ... ..	1	2
Tournapull-drawn scrapers ... ..	1	7
Motor graders ... ..	3	4
Blade graders ... ..	2	1
Excavators (19 R.B. and 10 R.B.) ... ..	2	3
Dumpers ... ..	8	18
Diesel rollers ... ..	3	3
Rollers tractor-drawn ... ..	3	3
Tar tanker and sprayer (each) ... ..	—	1
Tar boilers ... ..	—	2

Also one Fordson tractor, face shovel ( $\frac{1}{2}$ -yard), Athey loader, compressor and mobile crane.

## 5. Work involved :—

*Grouted stone* : Runway and warming-up aprons. 144,450 square yards.

*Pierced steel plank*, mostly with base course of sand 3 inches thick.

Warming-up aprons	...	...	...	...	4,000 square yards
Taxi-tracks	...	...	...	...	38,700 square yards
Perimeter track	...	...	...	...	20,000 square yards
Dispersals	...	...	...	...	30,000 square yards

92,700 square yards

	Earth-works cu. yds.	Base coat. Stone 4 ins. and 3 ins. cu. yds.	Surface coat. Stone 1½ ins. cu. yds.	Chippings cu. yds.	Bitumen tons	Sand cu. yds.	Pierced steel plank tons
Runway ...	77,200	16,486	7,133	1,800	329	—	—
Warming-up aprons ...	13,600	5,834	2,188	550	106	1,060	84
Taxi-tracks ...	23,000	—	—	—	—	4,850	774
Perimeter track	23,550	—	—	—	—	2,560	426
Dispersals ...	15,000	—	—	—	—	4,500	632
Totals ...	152,350	22,320	9,321	2,350	435	12,970	1,916

## 6. Supply of materials

(a) Poor quality limestone 1½ miles from the airfield, supplemented by stone from other sources, at 10 and 13 miles distance.

Stone used :—4-inch gauged stone	=	17,721 cubic yards
3-inch gauged stone	=	3,637 cubic yards
1½-inch gauged stone	=	8,454 cubic yards
½-inch gauged stone	=	1,280 cubic yards
Dust ... ..	=	642 cubic yards

31,734 cubic yards

## (b) Transport of stone

Haulage to site, 3-ton lorries and Decauville railway.

Decauville Loading, by 19 R.B. excavator and partly by  
railway hand.

5 trains of 12 skips of 1 cubic yard capacity.  
Round trip, 3 miles, averaging 75 minutes.

Lorries (on water-bound roads in poor condition).

(i) Loading direct from crushers and occasionally\* by 19 R.B. excavators, into 3-ton tipping lorries, averaging 2½ cubic yards.  
Round trip, 3 miles, averaging 52 minutes.

(ii) Loading direct from chutes, D.4 Athey loader and hand loading into 3-ton lorries.  
Round trip, 26 miles, averaging 130 minutes.

## 7. Output of plant

- (a) *Scrapers*.—Cut and fill on runway.

77,200 cubic yards in 29.5 days by three D8+12-yard scrapers and four D7+8-yard scrapers, equivalent to 2,620 cubic yards per day.

Work done represented :—

12-yard scraper—46 cubic yards in one hour.

8-yard scraper—31 cubic yards in one hour.

- (b) *Tournapull-drawn scrapers*

Carrying sand from sea to dispersals, taxi-track and perimeter track, distance of round trip—three miles.

12,970 cubic yards of sand in 17.5 days were collected and carried by six Tournapulls representing an output, per Tournapull, of 12.3 cubic yards per hour on a three-mile round trip.

- (c) *Quarry plant outputs*

One 50-ton/hr. crusher    23,800 tons in 61 days = 31 tons per hr.

One 25-ton/hr. crusher    3,130 tons in 16 days = 12 tons per hr.

Two 10-ton/hr. crushers    1,890 tons in 31 days = 4 tons per hr.  
(each)

- (d) *Bitumen plant*

One 1,500-gallon sprayer, one 3,000-gallon tanker and two 1,000-gallon boilers.

329 tons of liquid bitumen (M.C. 3) were sprayed over an area of 68,970 super yards in two-coat work, and 14,450 super yards in one-coat work, in 130 working hours, including delays not attributable to the distributor.

Average per hour, 530 square yards in two-coat work plus 111 square yards in one-coat work.

## SECTION 89.—BITUMEN STONE.—PLANT MIX

The following specifications were adopted by U.S. aviation engineers, in the construction of bomber airfields, upon mixed loam soils in North Africa.

Climatic conditions : summer-dry, with heavy winter rainfall, rendering impermeable soil unfit for traffic.

- (a) *Formation*.—Natural soil fill for crown of 15 inches, 95 per cent. compaction, providing 1 per cent. fall across runway and shoulder. Width of runway 100 feet, with shoulders 40 feet each.
- (b) *Base course*.—4 inches of decomposed limestone ("caliche") compacted at optimum moisture content of 10 per cent. with wearing course of plant mix bituminous stone.
- (c) *Pavement*.—2 inches of stone crushed to 1 inch. Not more than 40 per cent. to pass the No. 4 sieve and not more than 5 per cent. to pass the No. 200 sieve. The aim was to produce this stone as crusher-run without screening.

## 5. Work involved :—

*Grouted stone* : Runway and warming-up aprons. 144,450 square yards.

*Pierced steel plank*, mostly with base course of sand 3 inches thick.

Warming-up aprons	...	...	...	...	4,000 square yards
Taxi-tracks	...	...	...	...	38,700 square yards
Perimeter track	...	...	...	...	20,000 square yards
Dispersals	...	...	...	...	30,000 square yards

92,700 square yards

	Earth-works cu. yds.	Base coat. Stone 4 ins. and 3 ins. cu. yds.	Surface coat. Stone 1½ ins. cu. yds.	Chippings cu. yds.	Bitumen tons	Sand cu. yds.	Pierced steel plank tons
Runway ...	77,200	16,486	7,133	1,800	329	—	—
Warming-up aprons ...	13,600	5,834	2,188	550	106	1,060	84
Taxi-tracks ...	23,000	—	—	—	—	4,850	774
Perimeter track	23,550	—	—	—	—	2,560	426
Dispersals ...	15,000	—	—	—	—	4,500	632
Totals ...	152,350	22,320	9,321	2,350	435	12,970	1,916

## 6. Supply of materials

(a) Poor quality limestone  $1\frac{1}{2}$  miles from the airfield, supplemented by stone from other sources, at 10 and 13 miles distance.

Stone used :—	4-inch gauged stone	=	17,721 cubic yards
	3-inch gauged stone	=	3,637 cubic yards
	$1\frac{1}{2}$ -inch gauged stone	=	8,454 cubic yards
	$\frac{1}{2}$ -inch gauged stone	=	1,280 cubic yards
	Dust ... ..	=	642 cubic yards

31,734 cubic yards

(b) *Transport of stone*

Haulage to site, 3-ton lorries and Decauville railway.

Decauville      Loading, by 19 R.B. excavator and partly by  
railway              hand.

5 trains of 12 skips of 1 cubic yard capacity.  
Round trip, 3 miles, averaging 75 minutes.

Lorries (on water-bound roads in poor condition).

(i) Loading direct from crushers and occasionally\* by 19 R.B. excavators, into 3-ton tipping lorries, averaging  $2\frac{1}{2}$  cubic yards.  
Round trip, 3 miles, averaging 52 minutes.

(ii) Loading direct from chutes, D.4 Athey loader and hand loading into 3-ton lorries.  
Round trip, 26 miles, averaging 130 minutes.

## 7. Output of plant

- (a) *Scrapers*.—Cut and fill on runway.

77,200 cubic yards in 29.5 days by three D8+12-yard scrapers and four D7+8-yard scrapers, equivalent to 2,620 cubic yards per day.

Work done represented :—

12-yard scraper—46 cubic yards in one hour.

8-yard scraper—31 cubic yards in one hour.

- (b) *Tournapull-drawn scrapers*

Carrying sand from sea to dispersals, taxi-track and perimeter track, distance of round trip—three miles.

12,970 cubic yards of sand in 17.5 days were collected and carried by six Tournapulls representing an output, per Tournapull, of 12.3 cubic yards per hour on a three-mile round trip.

- (c) *Quarry plant outputs*

One 50-ton/hr. crusher 23,800 tons in 61 days=31 tons per hr.

One 25-ton/hr. crusher 3,130 tons in 16 days=12 tons per hr.

Two 10-ton/hr. crushers 1,890 tons in 31 days= 4 tons per hr.  
(each)

- (d) *Bitumen plant*

One 1,500-gallon sprayer, one 3,000-gallon tanker and two 1,000-gallon boilers.

329 tons of liquid bitumen (M.C. 3) were sprayed over an area of 68,970 super yards in two-coat work, and 14,450 super yards in one-coat work, in 130 working hours, including delays not attributable to the distributor.

Average per hour, 530 square yards in two-coat work plus 111 square yards in one-coat work.

## SECTION 89.—BITUMEN STONE.—PLANT MIX

The following specifications were adopted by U.S. aviation engineers, in the construction of bomber airfields, upon mixed loam soils in North Africa.

Climatic conditions : summer-dry, with heavy winter rainfall, rendering impermeable soil unfit for traffic.

- (a) *Formation*.—Natural soil fill for crown of 15 inches, 95 per cent. compaction, providing 1 per cent. fall across runway and shoulder. Width of runway 100 feet, with shoulders 40 feet each.
- (b) *Base course*.—4 inches of decomposed limestone ("caliche") compacted at optimum moisture content of 10 per cent. with wearing course of plant mix bituminous stone.
- (c) *Pavement*.—2 inches of stone crushed to 1 inch. Not more than 40 per cent. to pass the No. 4 sieve and not more than 5 per cent. to pass the No. 200 sieve. The aim was to produce this stone as crusher-run without screening.

- (d) *Shoulders*.—Base course a minimum of 2 inches with a sealing coat of M.C.-0 bitumen (a cut-back with 23 per cent. kerosene or petrol) at 0.3-0.4 gallons per square yard.
- (e) *Runway seal course*.—A top seal course was laid, to reduce heat absorption, of crusher fines or sand spread at 20 lb. per square yard. This course was applied 24-48 hours after the paving and rolled into the surface by tandem or rubber-tyred rollers.
- (f) *Taxi-tracks and hardstandings*.—Hardstandings, turnouts and bends constructed to the same specifications as the runway, but the straight portions of taxi-tracks were given a base course of 5 inches and pavement of  $1\frac{1}{2}$  inches.
- (g) *Mixing*.—All mixing by means of Barber-Greene travelling plant. Binder: 7 per cent. M.C.3. A thin layer of natural soil was spread by hand over the grouted surface.

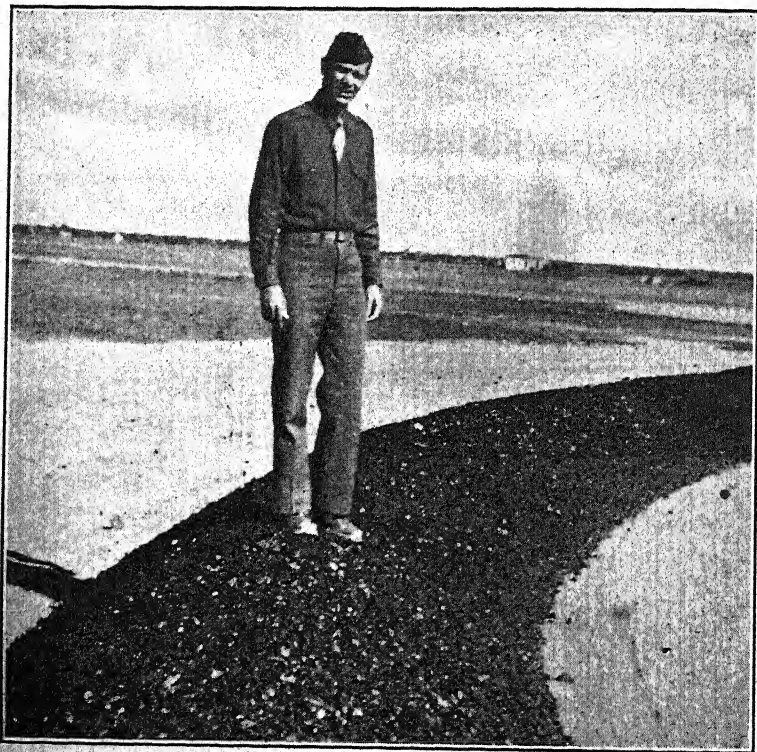


PLATE 47.—BARBER-GREENE BIT-STONE WINDROW  
ON TAXI-TRACK. TUNISIA

## SECTION 90.—BITUMEN-GRAVEL

1. Example of low-grade aggregate airfield constructed in the south of England.

The task comprised three runways totalling 4,400 yards in length, representing 220,000 square yards of paved area, for rapid completion.

2. With the time, plant and labour available, usual specifications could not be adopted. The following specification was accepted :—

3 inches clinker, base.

8 inches gravel from pit face.

3 inches tar-grouted flints.

The stone comprised a high percentage of flint from 3 inches to  $1\frac{1}{2}$  inches, and gravel from  $1\frac{1}{2}$  inches down to  $\frac{3}{8}$  inch, with a chalk and clay-like binder.

3. Approximate total quantities were :—

Clinker, 20,000 cubic yards.

Wall ballast, 45,000 cubic yards.

Washed flints, 20,000 cubic yards.

Tar, 350,000 gallons.

4. Work done :—

(a) Clinker was hand-spread and rolled to a consolidated thickness of 3 inches, by means of  $2\frac{1}{2}$ -ton rollers operating longitudinally and transversely.

(b) Foundations consisted of gravel "ballast" spread by hand and rolled in two layers, to a consolidated thickness of 8 inches. Success in the use of this material lies in strict control. The larger flinty aggregate is laid first, followed by the balance, composed largely of binding gravels.

The first layer should be rolled with 6- or 10-ton rollers, according to the weather, the second layer being consolidated with 10- or 12-ton rollers working both longitudinally and transversely.

(c) The grading of the surfacing consisted of a full tar-grouted coat of  $2\frac{1}{2}$ – $1\frac{1}{2}$  inches washed flints, laid to a consolidated thickness of 3 inches and surface dressed with  $\frac{3}{8}$ -inch chippings. All material was levelled and spread with a Class IV bulldozer, and half a dozen experienced spreaders followed up, taking out any minor irregularities. The surface was then rolled by 10- or 12-ton rollers, and grouted with No. 2 road tar, by pressure tank sprayer, at the rate of  $\frac{1}{2}$  gallon per square yard. A layer of  $\frac{1}{2}$  inch to  $\frac{3}{8}$  inch washed gravel was then spread at 250 square yards to the cubic yard and lightly rolled. A further application of smaller gravel,  $\frac{3}{8}$  inch to  $\frac{3}{16}$  inch, was spread two to three days after the grouting at the rate of 150 square yards to the cubic yard, and surface rolled true to shape. When the tar had set, a further application of tar was made at the rate of  $\frac{1}{2}$  gallon per square yard and  $\frac{3}{8}$ -inch chippings were spread at the rate of 250 square yards to the cubic yard, and the surface thoroughly rolled both longitudinally and transversely.

To avoid loose chippings on the runway, the surface was finally sprayed with tar at the rate of 6 square yards to the gallon and rolled.

## 5. Plant available for the work :—

Skimmers and excavators	... 11	Mechanical rammers	... 6
Mechanical loading shovels	... 3	Lorries	... 54
Bulldozers	... 3	Dumpers	... 14
Rollers	... 25	Horses and carts	... 20

## 6. Personnel employed :—

<i>Staff</i>	<i>Labour</i>	
Resident engineer	General foreman	... 1
Assistant resident engineer	Gangers	... 5
Plant manager	Sub-gangers	... 4
Storekeeper	Leading hands	... 7
Material checkers	Labourers	... 260
Two clerks		
Two timekeepers		

The unskilled labourers were casual workmen recruited locally.

## SECTION 91.—BITUMEN OR TAR—STONE

1. Base course of compacted gravel or crushed stone of varying thickness to suit sub-grade strength. For aprons, hardstandings and taxi-tracks, base consists of two 3-inch layers of gravel or water-bound macadam.

2. Surfacing is by either hot-mix asphalt or bituminous penetration, according to the availability of plant. With the penetration method more thorough surface dressing is necessary than with hot-mix.

- (a) Hot-mix.—Crushed stone aggregate, graded from 100 per cent. passing 1-inch screen to 10–25 per cent. passing 10 mesh. Heated between 200 degrees and 275 degrees F., mixed with the mineral filler and then with 4–6 per cent. bitumen, heated to 175 degrees–275 degrees F. Spread by mechanical finisher, with help of rakers, and rolled with tolerance of  $\frac{1}{4}$  inch under a 10-ft. straight edge.

Sealing coat of 90–93 per cent. of fine aggregate (minus  $\frac{1}{4}$ -inch screen), mixed with 5.5–10 per cent. bitumen and spread at 35 lb./square yard.

- (b) Alternative: bitumen penetration wearing course. Crushed stone minus  $2\frac{1}{2}$ -inch and plus 1-inch circular screen, laid and compacted on prepared base to a depth of  $2\frac{1}{2}$  inches. Bitumen is sprayed on at rate of 1.25 to 1.40 gallons per square yard. The surface is immediately covered by a layer of stone passing the 1-inch and retained on  $\frac{3}{8}$ -inch circular screen, rolled until all voids are filled, and sealed with bitumen sprayed at the rate of  $\frac{3}{4}$  gallon/square yard covered with finer stone and again rolled.

- (c) Surface dressing: bituminous binder applied at  $\frac{1}{4}$ th to  $\frac{1}{2}$ th gallon/square yard, covered with clean dry aggregate ( $\frac{1}{2}$  inch down) and rolled. Subsequently, a second coat of  $\frac{1}{4}$ th gallon/square yard of bitumen covered with 15 lb. of sand.

## SECTION 92.—BITUMEN—GRADED STONE

1. Carefully graded stone with an emulsion armour coat has been used occasionally in airfield construction to reduce the tonnage hauled and to facilitate work during wet weather. In America, this material is called "theoretically graded stone," representing a combination of aggregate sizes, in which the voids between larger particles are progressively filled with smaller particles and so on down to minus 200 mesh dust.

2. Airfields have been built in England with a thickness of 5 inches graded stone, for fighter and ultimately for bomber service. Two examples, representing a total of 400,000 square yards in runways and tracks, are described below :—

- (a) A 3-inch layer of quarry waste, rolled into a sub-grade of permeable sand. This stabilization of surface was chiefly required to assist transport during the construction period.
- (b)  $4\frac{1}{2}$  inches of graded stone, laid and consolidated in two layers. Sealing in both cases with tar or bitumen under a wearing course which consisted of a  $\frac{3}{4}$ -inch armour coat of  $\frac{3}{4}$ -inch chippings and bitumen emulsion.

3. The bottom layer of (b),  $2\frac{1}{2}$  inches consolidated of graded stone ( $1\frac{1}{2}$ -inch to  $\frac{1}{4}$ -inch), was spread at the rate of 13.4 square yards to the ton, with an 8-foot blade grader. Fines,  $\frac{1}{4}$  inch to dust, were then spread at 29 square yards per ton. The stone and fines were mixed by chain and spike harrows, watered, graded and rolled.

The top coat,  $1\frac{1}{2}$  inches of consolidated 1-inch to  $\frac{1}{4}$ -inch stone, spread by blade grader at 15.4 square yard to the ton, followed by fines,  $\frac{1}{4}$  inch to dust at 42 square yards to the ton, all harrowed and compacted.

Sealing was done with a spray of cut-back—a low viscosity tar-bitumen compound (180 degrees F.) at 4 yards to the gallon.

An "armour coat" of  $\frac{3}{4}$ -inch granite chippings was then spread at 60 square yards to the ton, sprayed in two days' time with quick-breaking bitumen emulsion at 3 yards to the gallon and covered with  $\frac{3}{4}$ -inch granite chippings at 90 square yards to the ton. After rolling, a second emulsion spray at 4 yards per gallon, followed by dusting at 180 square yards per ton and final rolling.

For heavy service, this armour coat should be increased to 1 inch or  $1\frac{1}{2}$  inches thick.

4. **Grading.**—The permissible reduction in thickness of material, which calls for better facilities for preparation than normal hardcore, is due to the properties of well-graded stone. Voids are less and the dust, acting as a binder, adds mechanical strength to the layers of stone.

A grading recommended for this type of construction is as follows :—

	Per cent.
1-inch to plus $\frac{3}{4}$ -inch	30
Minus $\frac{3}{4}$ -inch to plus $\frac{1}{4}$ -inch	23
Minus $\frac{1}{4}$ -inch to 10 mesh	14
Minus 10 to 50 mesh	13
Minus 50 to 200 mesh	8
Minus 200 mesh	12
	<hr/> 100 <hr/>

The inclusion of a substantial clay fraction is important.

5. Finally, a coarse-textured asphalt coat, of  $\frac{1}{2}$ -inch stone chippings, straight hot bitumen and some limestone dust, was added.

6. The maximum rate of progress attained, under war difficulties, was 4,000 square yards per day, but the average was much lower.

### SECTION 93.—BITUMEN—HEAVY SOLING PRACTICE

1. Road construction methods, involving the use of heavy soling, are generally unsuitable for war-time needs owing to the big tonnages involved and the comparatively slow speed of work. Many such airfields, however, representing several million square yards of pavement, have been built in operational areas in Middle East under the following conditions :—

- (a) Bad cotton soil sites, without any alternative.
- (b) Availability of big supply of local labour, experienced in road work.
- (c) Demand for heavy service during four winter months with rain-fall of 20–40 inches.
- (d) Long period of dry weather available for construction, during which adequate fair-weather landing grounds could be used.
- (e) Local bitumen supplies.
- (f) Some local transport.

2. For the most treacherous cotton soil, the usual specification was :—

Underlay of coarse sand or gravel	...	...	8 inches
Limestone soling, well shaped, laid and chinked	...	...	8 inches
Grouted metalling	...	...	2½ to 3 inches
Sealing coat, chippings	...	...	½ inch

3. A two-runway airfield, with taxi-tracks and standings, totalling 240,000 square yards, represented 150,000 tons of stone, gravel and sand.

Economic speed of work was 2,000 square yards per day, employing about 800 supervisors and labourers, sub-divided as under upon typical tasks :—

Formation	...	...	...	...	...	110
Underlay	...	...	...	...	...	150
Soling	...	...	...	...	...	180
Metalling	...	...	...	...	...	110
Grouting	...	...	...	...	...	60
Sealing coat	...	...	...	...	...	60
Kerbstones	...	...	...	...	...	50
Drainage	...	...	...	...	...	70

In addition, 500 labourers were employed in quarries and on crushers.

4. The conditions prevailing in such a task are characteristic of the Middle and Far East when it is practicable and economically advisable to make full use of local resources.

5. For satisfactory progress upon a big airfield sited on bad cotton soil, a four months' spell of fine weather is essential. But where risks must be taken and heavy maintenance demands are relatively unimportant, any thin impervious covering—such as sand-bitumen mix—represents a good speculative alternative, provided the cotton soil can be covered before deterioration by winter rains.

## CHAPTER 14

## CONCRETE RUNWAYS

## SECTION 94.—GENERAL

1. It is generally accepted that the best form of construction for heavy aircraft and permanent heavy service comprises a concrete pavement, not less than 6 inches thick, laid upon a sound base course.

2. Outside the United Kingdom, India, and U.S.A., there has rarely been occasion to build military airfields of such durable features. Short-term wearing qualities in theatres of war are held more prominently in view than bearing capacity or life under practically unlimited repetitions of stress.

3. In the design of concrete runways for civil aviation, a factor of safety is applied upon an assumption of failure through fatigue induced by stress repetitions over a life of 30 years. In operational areas good service for two winters, without heavy maintenance, may be considered a reasonable objective.

4. Military engineers may be called upon to build runways, aprons, turning circles and hardstandings in concrete, because the resources required are found to be the most readily available, or because the sub-grade strength cannot be brought up to the standard necessary to support a flexible pavement by any better means.

5. Under war conditions abroad, the use of concrete specifications is commonly restricted by a shortage of crushing plant of efficient capacity.

6. In the following Sections, examples will be given of common practice in airfield construction, and attention drawn briefly to features characteristic of such tasks. Normal practice is covered fully in Military Engineering, Volume XIV, "Concrete" and Volume V, Part I "Roads."

## SECTION 95.—PORTLAND CEMENT APPLICATIONS

1. The type of rigid pavement, utilizing Portland cement, will be selected, in light of local conditions and resources, from the following:—

- (a) Premixed concrete, with or without reinforcement, usually containing about  $\frac{1}{4}$  ton of cement per cubic yard.
- (b) Cement grouting or "Colcrete" containing  $\frac{1}{8}$ – $\frac{1}{4}$  ton of cement per cubic yard.
- (c) Soil cement, containing 8 to 14 per cent. of cement by weight of the dry soil.

2. Lean-mix roller-compacted concrete, containing  $\frac{1}{4}$  to  $\frac{1}{2}$  ton of cement per cubic yard, may give good service as a base-course on permanent airfields.

## SECTION 96.—CONCRETE RUNWAYS (ENGLAND)

The following extracts are from a typical specification for unreinforced concrete runways in United Kingdom.

1. On completion of excavation, finished formation levels are obtained by blinding the excavated surface with ashes or gravel, if the site is dry. When the site is naturally wet, or liable to weakening by bad weather, during construction, mass concrete (12:1) may be used to protect the sub-grade and form a base-course for the concrete slabs.

2. Concrete specifications from which selections are made for different tasks, are classified:—

- "A" 1:8 mixed aggregate, maximum 2 inches.  
 "B" 1:6 mixed aggregate, maximum  $1\frac{1}{2}$  inches.  
 "C" 1:5 mixed aggregate, maximum  $\frac{3}{4}$  inch.  
 Precast 1:4 mixed aggregate, maximum  $\frac{3}{4}$  inch.

Grade "B" is normally used in runways. The following thicknesses are adopted, for general heavy service, unless exceptional loads are specified:—

Strong sub-grade	...	...	...	...	6 ins.
Medium soft clay or fine sand	...	...	...	...	7 ins.
Soft clay	...	...	...	...	8 ins.

Bays—24 feet by 16 feet 8 inches.

Reinforcement is provided in pen walls and precast drain covers.

3. For camouflage purposes, a textured surface coat of open texture, free from shine in "pervious" asphalt can be advantageously applied. Texture depth, not less than 0.75 inch. On a concrete runway, this coat is 1 inch thick, consolidated.

Grading of aggregate:—

$\frac{3}{4}$ to $\frac{1}{2}$ inch	55-65 per cent.
$\frac{1}{2}$ to $\frac{3}{8}$ inch	25-30 per cent.
$\frac{3}{8}$ inch to 200 mesh	10-15 per cent.
Filler	4-6 per cent.

Dried and mixed at 120 degrees F. with tar binder—10-11 gallons per ton. Roller for consolidation not less than 8 tons.

## SECTION 97.—CONCRETE AIRFIELD FOR SUPER HEAVY AIRCRAFT

1. In illustration of methods and designs adopted for the construction of a big airfield, serving all types of aircraft, including the heaviest in immediate prospect, reference will be made to a few of the main features characterizing a task in Southern England.

2. The airfield is sited upon extensive flats of loamy soil overlying a gravel sub-soil at 3 to 4 feet, which is used as base-course sub-grade.

- (a) Main runway, 3,000 yards by 100 yards with provision in general layout for extension to 5,000 yards. Two secondary runways, 2,000 yards by 100 yards with provision for extension and for an additional runway.

Graded strips on each side of runways, 75 yards wide.

Taxi-tracks—100 feet wide.

- (b) Base course.—Base course built up to required grade in 9-inch layers of gravel, compacted by sheepfoot rollers.

- (c) *Surface course*.—12 inches of reinforced, vibrated concrete. Graded aggregate,  $\frac{3}{4}$  inch and  $\frac{3}{8}$  inch. Maximum strength 4,000 lb., after 28 days. Expansion joints are provided.
- (d) *Drainage*
- (i) Runways—6-inch drain increasing to 36 inches on both sides of runway. Catchpits every 75 feet. Concrete haunches for larger pipes.
  - (ii) Taxi-tracks.—Drainage as for runways, but only on one side of taxi-track.

Runway and taxi-track drainage merges into three 48-inch drains culminating in four 54-inch drains, thereby allowing for future extension of the system. Final discharge is through an oil trap into a natural water course. No drainage under runways or taxi-tracks. Herringbone drainage, where necessary, at side of runways.

### SECTION 98.—REINFORCED CONCRETE (UNITED KINGDOM)

1. Reinforced concrete has not been used for runway and subsidiary pavements to the same extent as unreinforced concrete and other materials, but some millions of square yards have been laid, in England alone, in this type of construction.

Without detailed analyses of sub-grade, varying from well-drained sand to the worst of water-logged clay or made-up ground, and without close study of results under the test of time and service, no firm comparisons of practical value could be attempted.

2. Advantages claimed by engineers who have adopted reinforced concrete specifications are :—

- (a) *Speed*.—On indifferent sites, work may be commenced with less consideration of soil conditions, the additional flexural strength given by the reinforcement balancing minor weaknesses in the sub-grade.
- (b) *Economy*, notably in transport.—Where a construction stronger than 6 inches of plain concrete on 3 inches of ashes is required, the addition of a layer of reinforcement at 1s. 9d.—2s. per square yard, is an economical way of adding strength, and so aiding crack control.

3. The pavement has generally been made 6 inches thick, of 1 : 2 : 4 mix concrete, laid on 3 inches of consolidated ashes. On soft ground, rolled hardcore from 3–12 inches thick, and exceptionally more, is laid under the ashes. The paving is divided into slabs not more than 500 square feet in area, to allow for expansion and to take available sizes of steel fabric. Expansion jointing material between slabs  $\frac{3}{8}$  inch to  $\frac{1}{2}$  inch thick.

4. The usual reinforcement is high tensile 6-inch square mesh steel fabric in one layer, weighing 5.2 lb. per square yard and placed about 1 inch from the underside of the slab. Later opinion favours the placing of a single layer of reinforcement about  $1\frac{1}{2}$  inches from the top side of slab, to give greater strength at the corners and edges. Exceptionally, two layers have been used.

5. The concrete is covered with 1 inch of "pervious" asphalt or similar material for toning down or reducing wear on aircraft tyres.

6. The runways built have been from 1,000 to 2,400 yards in length, and 50 yards wide, with 75 yards of well graded turf on each side, with the usual perimeter tracks, 25 to 50 feet wide, ranging from three-quarters of a mile to two-and-a-half miles in total length.

Aprons, hard-standings, taxi-tracks and marshalling areas are all subjected to heavier stresses than runways. The tendency now is to make them 20-25 per cent. thicker than the runways to guard against their earlier failure.

**7. Quantities, labour and plant.**—For 1,000 yards of runway, average quantities have been :—

Excavation and clearing	...	...	...	20,000 cubic yards
Ashes or clinker	...	...	...	4,200 cubic yards
Concrete	...	...	...	8,400 cubic yards
Steel fabric (single)	...	...	...	51,000 square yards
Drainage	...	...	...	3,500 lin. yards

Labour :—

Average number of men employed ... .. 175

Plant—average quantity available :—

Skimmers and excavators	...	4	Graders	...	...	2
Scrapers, 8-yard	...	2	Lorries	...	...	20
Bulldozers and tractors	...	4	Dumpers	...	...	6
Concrete mixers, 14/10 yard	...	8	Rollers	...	...	3

**8. Time of construction.**—Nearly all tasks undertaken in England in reinforced concrete construction have been of high priority. A good speed has been attained, where adequate plant has been available, weather has been favourable, and where heavy preliminary work has been unnecessary.

Best results have been obtained upon runway tasks of over 100,000 square yards where the time lost on preparations and building-up routine efficiency is proportionately small.

An analysis of work done upon 22 airfields (33 runways) shows the following average working times :—

(a) 10 tasks less than 100,000 square yards: 4,400 square yards per week.

(b) 12 tasks 100,000 square yards and over: 8,400 square yards per week.

These figures include several tasks where progress was slow for reasons beyond control.

The most rapid achievement was upon a three-runway airfield, representing 222,000 square yards, completed in 10½ weeks, equal to 21,000 square yards per week. Specification, 6 inches reinforced concrete on 2 inches of hardcore with 1-inch pervious asphalt wearing coat. 10 per cent. of the task was done in unreinforced concrete 8 inches thick.

Under ideal conditions a 200,000-square yard airfield could be paved in three weeks using three double-drum pavers. Progress would depend upon the provision of adequate batching and spreading facilities, and uninterrupted supplies of aggregates, cement and water to meet a daily output of 1,800 cubic yards of concrete.

## SECTION 99.—CONCRETE CONSTRUCTION METHODS (U.S.A.)

1. Normal practice in the construction of important runways in America involves the use of mechanical pavers for mixing, placing, spreading and finishing.

2. Common features of practice are as follows:—

- (a) *Cement*.—Standard Portland cement, except occasionally for the last strips, when rapid hardening ("high—early—strength") cement may be employed to expedite the opening of the runway to service. Cement content:  $5\frac{1}{2}$  bags (517 lb.) per cubic yard of finished concrete.
- (b) *Aggregate*.—Average 40 per cent. fine to 60 per cent. coarse, adjusted to give a workable relatively dry plastic mix having a slump of 2 inches if consolidated by machine, or 3 inches for hand tamping and blading.
- (c) *Water*.—Ratio in concrete for runways, not more than 6—U.S. gallons per bag (94 lb.) of cement.
- (d) *Equipment*.—Plant for crushing, washing and screening is at the aggregate pit. Batching plant is located at the mixing plant, or at an intermediate point. Cement is loaded on to the batch trucks or dumpers at any convenient point between the batcher and paver, or may be batched with the aggregates when travelling mixers are used.
- (e) *Paving*.—Strips are 20–25 feet wide, depending on the width of the spreader and finisher available. Work is done on alternate strips for the full length of the runway, in opposite directions successively, until the other side of the runway is reached, when the unpaved strips are filled in.
- (f) *Paver*.—Each batch is dumped from the batch truck into the skip on the paver and elevated to the mixer drum. Water is controlled by a metering device.
- (g) *Placing*.—The mix is discharged into a bucket which travels on a swinging boom.
- (h) *Spreading*.—The spreading machine travels on the forms (pre-fabricated steel members) behind the mixer and distributes the concrete across the strip by a moving blade or screw, behind which is a strike-off bar to bring the surface to its approximate final level.
- (i) *Finisher*.—The finishing machine rides on the forms in the same way as the spreader. It has a front screed, vibrator and rear screed. Any final irregularities are smoothed out with hand screeds during the other hand operations, such as edging and trimming joints.
- (j) *Joints*.—Construction and expansion joints are provided. Usual spacing of longitudinal expansion joints, 75 to 100 feet, and of transverse expansion joints, 50 to 120 feet. After curing, joints are cleaned out and filled with hot bituminous joint filler such as a heavy grade of tar or bitumen.

3. In American practice, the outside edges of slabs, along the longitudinal expansion joints, are thickened over, to a width of 10–15 inches, to provide the additional pavement strength where most required.

## SECTION 100.—CONCRETE RUNWAYS (U.S.A.)

1. Military airfields in U.S.A., for heavy bomber or transport aircraft, are constructed in a wide range of types, in concrete or bituminous materials.

2. Some examples of concrete construction are given below, to illustrate trends of current practice, in which the consistent strengthening of haunches and absence of reinforcement, with utmost stability in the base-course, are the outstanding features :—

- (a) Runways, totalling 375,000 square yards, in concrete of 7 inches minimum thickness, have been completed by U.S. Army engineers in 70 days.
  - (i) The task represented the regrading and enlargement of a small airfield of bituminous construction. More than 180 acres of woods were cleared and 260,000 cubic yards of soil removed.
  - (ii) The sub-grade was a well-drained sand, good enough as a foundation for concrete, but a stabilized sub-base of gravel-clay increased speed of work by providing a hard surface for lorries used in construction. The sub-base was 5 inches thick.
  - (iii) The three 1,667-yard runways were each constructed in six 25-foot wide concrete lanes of 10-7-10-inches cross-section. Dowelled transverse expansion joints, pre-moulded, were placed at every 100 feet, dummy contraction joints at every 20 feet, and longitudinal dummy contraction joints down the centre of each lane. Joints between lanes were of the keyed, tongue and groove type.
  - (iv) The concrete mix design was 510 lb. to the cubic yard to give a compressive strength of 2,500 lb. at 28 days.
  - (v) Gravel-clay for the shoulders was produced at a local gravel-pit by two portable crushers, into which the necessary clay was fed to give the soil mixture a "plasticity index" of 8-12. The shoulder material was kept 2 inches below the final level, except at runway edges, to allow for addition of topsoil and seeding.
- (b) A heavy bomber concrete runway, in the Western States, 1,940 yards long by 67 yards wide, was built at the rate of 4,500 square yards per day. The 25-foot lanes had an 8-6-8-inches cross-section, with the 6-inch thickness to within 2 feet of each side and a dummy joint down the centre. The constant checking of water content was held to be extremely important, as the finished concrete had to be subjected to heavy loads. The mix was 470 lb. of cement to a cubic yard of concrete.
- (c) A big air-base, with three 1,850-yard runways and parking space for 1,000 aircraft, was built in 90 days, employing both concrete and bituminous specifications. On two of the runways, and the middle 600 yards of the third, a central strip of 50 yards in width was surfaced with unreinforced concrete slabs, 12½ feet wide, with a 10-8-10-inches section, on a crushed rock sub-base.

(d) One of the biggest airfields in N.E. America, built on a sandy plateau, was given a base-course of 4 inches of compacted gravel, surfaced with 6 inches of concrete; slabs were unreinforced except for a bent  $\frac{1}{2}$ -inch bar at each corner.

3. The American practice of strengthening the haunches of the cross-section calls for grading to varying thicknesses and necessitates special plant. Normal United Kingdom practice is to retain a constant cross-sectional depth and to rely on load transference devices to take excess stress developed at joints.

#### SECTION 101.—CONCRETE RUNWAYS FOR SUPER-HEAVY BOMBERS (U.S.A.)

1. The construction of concrete runways for super-heavy bombers is a task of such magnitude and importance that close estimation of engineering requirements is essential. Normal war-time risks are not acceptable. The maximum weight of the "B.29," loaded, is 130,000 lb. Track width is  $31\frac{1}{2}$  feet; wing span 141 feet and overall length 99 feet.

The B.29 is equipped with dual wheels. It has been determined in America that for dual wheels, as opposed to single, the wheel loading can be reduced by 25 per cent. in calculating the required thickness of a flexible, bituminous pavement. In concrete slab construction, favoured for such heavy service, a wheel-loading of 60,000 lb. is taken.

2. Concrete pavement thicknesses, for this loading, are given below for different types of sub-soil. Thicknesses refer to the interior of slabs and not the edges, which are thickened.

<i>Soil group</i>	<i>Minimum thickness, inches</i>
A.—Gravel and gravelly soils down to well-graded sand-clay mixtures ... ..	9
B.—Poorly graded sands down to inorganic silts and very fine sands ... ..	10
C.—Clays, inorganic and sandy or silty clays down to the weakest type of clay capable of compaction by normal methods ... ..	11

These values are based on the following assumptions:—

(a) Region not subject to heavy frosts.

(b) Scientifically compacted sub-grade.

(c) Thickness may be reduced in groups B and C to a minimum of 9 inches if a well compacted 6-inch base-course of binding gravel is laid or an 8-inch base-course of well-graded sand.

(d) Concrete breaking strength (28-day), in flexure, of at least 600 lb. per square inch. If strength 500 lb., 1 inch is added to thickness, and if over 700 lb., 1 inch reduction in thickness is allowed.

3. If the region is subject to frost, specifications are:—

<i>Average depth of frost</i>	<i>Thickness of base course</i>		<i>Thickness of concrete pavement</i>
48 inches ... ..	18 inches	and	9 inches
36 inches ... ..	12 inches	and	9 inches
24 inches or less, but not less than pavement thickness. }	6 inches	and	10 inches
	or		
	12 inches	and	9 inches

## Assumptions :—

- (a) Soils subject to frost action are well-graded soils containing more than 3 per cent. of particles less than 0.02 mm. in size, or if uniformly graded, containing more than 10 per cent. of such particles.
- (b) The base course material must be of a type unaffected by frost action.
- (c) Thickness of concrete will be increased or decreased, on breaking strength tests, as specified for non-frost construction.

## SECTION 102.—CEMENT GROUT (COLLOIDAL CONCRETE)

1. This method is recommended as an alternative to ordinary concrete construction in certain circumstances. It was widely adopted for runway work in Northern France, during the severe winter of 1939-40. Nine airfields were wholly or partly constructed by this method.

The process consists of spreading a layer of macadam, hardcore or similar material on the prepared formation and filling the interstices with a cement-sand grout, intimately mixed by a proprietary machine known as the "Colcrete" mixer. Owing to the influence of frost, the chalk of Western France was not wholly suitable as an aggregate during the severe winter of 1939-40.

2. Advantages and disadvantages must be balanced in the light of local conditions.

## (a) Advantages :—

- (i) The method is rapid and demands light and easily transported plant.
- (ii) Frosty weather does not bring all work to a standstill—the spreading of aggregate can be continued.
- (iii) A wide range of aggregate sizes is practicable.
- (iv) A good all-weather surface is provided.
- (v) Little of the labour need be skilled.

## (b) Disadvantages :—

- (i) Colloidal construction gives a weaker surface than pre-mix concrete.
- (ii) Weak patches are liable to occur unless work is done under closer supervision than commonly practicable for hasty jobs in war.
- (iii) Large quantity of cement required for the strength attained.

3. The mixer consists of two cylindrical tanks mounted vertically side by side. A rotor in the base of each is driven by a 10 h.p. I.C. engine. In the first tank the cement is finely dispersed in the water and the mix is passed at high speed through a narrow outlet into the

second tank, where sand is added and mixed with the water-cement grout. Finally, the finished grout is pumped to the work by the rotor in the second tank. The power unit and tanks forming the mixer are mounted on a chassis fitted with pneumatic-tyred wheels. The whole assembly weighs 12 cwt.

4. The aggregate should consist of a variety of hard, clean broken materials (*e.g.*, slag or heavy brick rubble) which will not float on the grout. Its weight must not be less than 125 lb. per cubic foot. If lighter materials are used, floating may be prevented by allowing a shallow layer of grout to set before filling to the full depth.

The size of the aggregate is immaterial provided that the dimensions of pieces are slightly less than the thickness of the runway, so that the grout will float over the top of the aggregate and form a continuous waterproof skin, not less than  $\frac{1}{2}$  inch thick. The consumption of grout will be reduced, however, if the aggregate is well graded in size, varying from 3-inches to 1-inch gauge. On no account should much material less than 1-inch be used, as in such cases penetration of the macadam can only be achieved by using a watery grout, too weak for durability.

The most suitable sand is composed of clean, rounded grains. Sand from stone crushers gives a harsh grout, which does not penetrate easily and is liable to form voids. All sand should pass a No. 7 B.S. sieve, with an insignificant proportion passing 100 mesh. Any stones in the mix are liable to jam the rotors.

5. Chalk is commonly found of sufficient hardness and imperviousness to be used as aggregate in place of macadam, provided measures are taken to ensure a sound sub-grade and to exclude all moisture from entering the chalk. This is best effected by covering the sub-grade with a layer of grout about  $\frac{1}{2}$  inch thick which is allowed to set before the chalk is distributed. The sides are similarly sealed by placing  $\frac{1}{2}$ -inch thick boards on the inner faces of the forms, subsequently withdrawing them after the chalk has been grouted and filling the space with grout. After the grouted chalk has set, a surface coat is applied.

Owing to its comparatively soft nature, the chalk must not be walked on during construction. Small pieces broken off might interfere with the penetration of the grout. To prevent absorption of water from the grout, the chalk must be well wetted immediately before grouting. In any case, the use of chalk demands constant control of quarry production to ensure correct and consistent density of stone.

6. The sub-grade or sub-base must be as dense as possible to check penetration of the grout. Open places in the surface should be closed by binding them with sand or other fine material.

The forms should be laid in the normal manner, care being taken that all joints are watertight, to prevent loss of grout. The aggregate is spread between the forms by a small bulldozer, motor grader or by hand, using stone forks and rakes. The level must be carefully checked by working a straight edge off the tops of the forms.

The mixer should be placed approximately at the centre of an 80-yard length of runway, this length being grouted in one operation by means of a single length of rubber hose, 2 $\frac{1}{4}$ -inch diameter, attached to the mixer outlet.

- (c) Citrus is generally planted on loamy or clayey sands in Palestine and E. Cyprus, but elsewhere (e.g., Sicily) loamy soils are used. Seldom, however, is citrus planted on sand and never on heavy clay.
- (d) Olives are seldom found on sand, and never on clay in Palestine, Syria, or Cyprus. More often, they are planted on shallow calcareous and rocky ground, whereas the heavier and deeper soils are reserved for grain.
- (e) In summer-dry Mediterranean countries, grain is never sown on sandy soils because of their low water-holding capacity. This is not the case further north where a more even rainfall distribution compensates for this deficiency.
- (f) In the desert, scrub indicates a silty sand, or in Italy an impervious red clay ("barragge").
- (g) Cotton may indicate the notorious "cotton-soil," badly drained silty clay, readily serviceable in the dry season and extremely difficult to deal with in the wet.
- (h) Rushes and willows establish a high water level, which prevents, by drowning of roots, the cultivation of fruit or grain.
- (i) Bracken and gorse favour a well-drained soil.
- (j) In the East, rice is associated with seasonal flooding and an underlay of hardpan.
- (k) Wheat usually indicates non-slaking clay.
- (l) Bare land in the midst of cultivation may denote slaking clay or seasonal flooding; in arid districts, the presence of some troublesome alkali.

3. Generally speaking, in summer-dry districts, striking differences in vegetation are associated with differences in soil types. In districts of more evenly distributed rainfall, vegetative distinctions are less pronounced, and in very humid regions may be almost indeterminable.

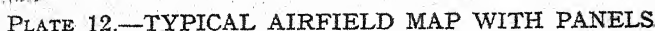
#### SECTION 46.—ENGINEER REPORTS AND MAPS

1. No standard form of engineer progress report, covering all types of construction will be satisfactory. Skeleton forms will be compiled by the responsible engineer formation or unit, appropriate to the physical conditions and urgency of the task, and the opportunities for close recording of progress without waste of time and effort. Standardization of reports within an area where methods are comparable is, however, of obvious importance.

It is a constant engineer responsibility to report progress of work, clearly and speedily, and to record results in some simple form for Air Force formations and Army staffs.

2. Rapid collection and distribution of information, during an advance, can be most satisfactorily effected by means of key maps, on a scale of about 1:500,000. Upon the margins of these maps, up-to-date replaceable panels of airfield plans, on a scale of about 1:100,000, are affixed.

Panels should show all essential features of completed runways, strips, taxi-tracks, dispersal, servicing facilities, and accommodation. Outside terrain should be covered for about 1 kilo beyond the area of construction.



3. Detailed tabulations, giving the particulars of each airfield, may also be required for despatch to higher formations and for permanent records, but the graphic method is more serviceable in operations, when heavy paper-work is urgently avoided. Schedules are difficult to amend for individual items, and the re-issue of complete new sets, for the large number of airfields covered in an army area, is likely to be too infrequent to meet exacting demands for current accuracy.

4. The graphic representation appeals particularly to air staffs and operational units. Airfields are so large and far apart, that their location can be reliably indicated upon 1 : 500,000 key maps of rough draughtsmanship without fear or any confusion of identity.

## CHAPTER 6

## DRAINAGE OF AIRFIELDS

## SECTION 47.—INTRODUCTION

1. The technical problems of airfield drainage are often the most pressing and complex with which the engineer has to deal. The constants are few and the many variables are generally difficult to assess.\* The correct interpretation of soil and other physical conditions, and the adoption of suitable drainage methods, may be essential for the continued serviceability of a field. Skilful work, or the avoidance of needless elaboration, will always be profitable.

2. The engineer must know his job. He must be confident in his decisions, not only to attain success and economize resources, but in order to convince those who may be asked to meet unwelcome demands at the expense of other tasks of more obvious urgency. He obtains a high priority when he calls for transport, equipment, and materials directly contributing to the creation of runway or dispersal areas. Less support may be forthcoming for protective measures against the ill effects of rainfall seepage or a rising water table.

3. The geologic origin of the wide flats necessary for the successful siting of big airfields, is commonly associated with unfavourable water characteristics. The absence of heavy undulations and erosion channels connotes poor run-off, whilst highly permeable soils are generally unstable. Low-lying areas which present the most favourable features from the flying and rapid surfacing aspect, will often form a natural repository for water from higher ground.

4. It is common experience to have to make drainage schemes conform to some predetermined layout, in the pattern of which the drainage features play small part. In war, the first demand is for speed in construction of landing and dispersal facilities, where flying considerations are good or passable, and locations are tactically suitable. The risk of future unserviceability, due to heavy storms or even normal rain, will often be accepted or ignored.

## SECTION 48.—GENERAL CONSIDERATIONS

1. In an operational area abroad, the main factors governing the drainage problem, upon a particular site, are the following :—

- (a) Topographical features, with special reference to contours and natural drainage within the airfield area. Drainage systems must be considered in relation to the natural drainage of the area and be designed to fit into it. Interference with the natural drainage of an airfield is a common source of trouble.
- (b) Rainfall probabilities, expressed in seasonal distribution and storm intensities.
- (c) Soil characteristics, disclosed by survey profiles, analysis, and observation.
- (d) The water-table (surface of a subterranean lake) and its seasonal changes of level.
- (e) Time and facilities available for work and the degree of immunity from flood-risk demanded operationally.

2. The drainage system must be laid out in order to remove all surface water from the operating areas, as rapidly as possible, without causing erosion. Standing water, even outside the runways and taxi-tracks, is a direct menace to aircraft and, if allowed to remain, may lead to detrimental softening of border strips or of track sub-soil. Water lying on paved surfaces is a menace to pilots, blinding their wind-screens or even damaging their flaps.

3. Types and dispositions disclosed by the soil profiles influencing layout and methods of drainage, are as follows :—

- (a) *Uniform and pervious soil.*—With such favourable conditions, not often found, artificial drainage may be wholly unnecessary.
- (b) *Uniform and impervious soil.*—This condition is common. It becomes urgent to remove runway water as soon as possible, but sub-drainage is unlikely to be needed. The clay-loam or "cotton-soil" group of soils, so prevalent in summer-dry regions of the Mediterranean, fall into this class. Such soils become practically impervious after the filling of cracks and saturation by the early winter rains.
- (c) *Pervious soil above and impervious below.*—These conditions may demand sub-drains just above the impervious layer, unless it is deep enough to cause no trouble.
- (d) *Impervious soil above and pervious below.*—This condition may be met by surface drains cut through a thin top layer. If this top layer is very thick, the existence of the permeable soil below may have no practical importance.
- (e) *Irregular disposition of pervious and impervious beds.*—Irregular deposits can only be dealt with in the light of the ascertained conditions. Such deposits may well be the most troublesome type and call urgently for sub-drainage, especially where heavy frosts prevail.

4. A commonly adopted target in the design of drainage systems upon military airfields is the removal in three hours of (a) the maximum rainfall to be expected in one hour, or (b) the normal daily rainfall. Rainfall intensity figures, for many regions, show such extreme variations that only the expectation of serious danger or loss of service from flooding, would justify full measures against the results of abnormal storms.

A storm assumption in excess of average expectations would be justified only as a safety factor. But however accurate this rainfall estimate, all calculations based upon it are liable to be highly conjectural, as applied to the capacity of drains and pipes hastily installed under war conditions.

Lacking data for rain intensity at specific localities in regions where the annual figures are known, acceptable assumptions of drainage capacity requirements can be made by deduction. In countries with sharp seasonal variations, as in North Africa and the East, a single day's rain will normally vary from 5 per cent. of the annual figure, where precipitation is moderate, to 10 per cent. for regions of heavy rain.

In England and Western Europe, with a higher number of rain-days of lower intensity, more evenly distributed throughout the year, these proportions are reversed. A safe assumption, without reference to any particular site, would be a single day's rain of 8 per cent. of the annual precipitation, where low rainfall prevails down to 4 per cent. for West Coast regions recording over 100 inches annually.

## SECTION 49.—RUN-OFF

1. Run-off plus percolation equals rainfall, the effects of evaporation and plant transpiration being of no account during storm periods. Percolation estimates will be heavily affected by the records of rainfall preceding the storm. At the beginning of a wet season or after a fine spell, percolation is great compared with subsequent phases when surface saturation retards the process. Run-off percentage increases with storm duration, for similar reasons.

The following table (U.S.A.) gives a picture of probabilities, which is wide enough for application to any other known conditions :—

Table VI.—Percentage of run-off under various conditions

Area type	Percentage of run-off	
	5-min. storm	2-hour storm
Runway or landing lane :—		
(a) Compacted soil	50%	90%
(b) Gravel or crushed stone	60%	100%
(c) P.S.P. over sand	25%	50%
(d) Bitumen surface	90%	100%
Apron or flight strip :—		
(a) Sand	20%	40%
(b) Loam	40%	60%
(c) Clay	60%	90%
Natural soil :—		
(a) Sand	20%	30%
(b) Loam	40%	60%
(c) Clay	60%	90%

The factors are based on a maximum 2 per cent. slope for natural surfaces. For steeper slopes, found outside the developed landing area, the run-off percentage should be increased by 2 per cent. for every increase of 2 degrees.

2. An illustration of the use of the above table, to determine run-off and consequent rate of discharge at critical points, may be given in the case of a P.S.P. crowned runway, 2,000 yards by 50 yards, upon compacted sand underlay or base course. It is required to deal with 2 inches of rain in two hours. Assume a drain on each side of the runway, in two lengths of 1,000 yards, graded toward the centre; a cross-drain under the runway and a main outlet channel collecting the total quantity.

The catchment area of the whole runway is 900,000 square feet. Assuming 40 per cent. run-off this gives 60,000 cubic feet of water in two hours, or 0.83 cubic feet per second or cusecs at the main outlet.

The capacity of each of the four lengths of side drain, collecting water from the runway and delivering to the transverse system, would require to be greater than 0.2 cusecs at its lower end, and the cross-drain greater than 0.4 cusecs; the main outlet would be designed to carry the total flow.

3. In developed areas, it is commonly possible to obtain direct evidence of maximum run-off by an examination of local water courses, natural or artificial, serving the flats before joining any storm-water

channels from higher ground. In undeveloped countries any area of flat ground big enough for airfield sites, without deep erosion channels, is likely to have a low run-off.

The important storm is the one that lasts long enough for water falling on the farthest portion of the runway to reach the outlet. Time of concentration is the essence of design of storm-water or sub-drainage of runways.

#### SECTION 50.—SURFACE DRAINAGE

1. The two purposes of surface drainage, which may be of open or sub-drain type, are the rapid collection and removal of water falling on the operational surfaces, and the prevention of flooding by water which might flow from any source on to portions of the field in use.

2. At safe distances from the cleared areas or where they do not constitute the only obstacle, big open ditches can be advantageously employed, not only to intercept all ground and surface water and to act as outfall ditches, but also, at times, to assist in lowering the water-table, with good results upon soil stability throughout the airfield.

3. Generally speaking, military engineers are better equipped to undertake rapid work upon open ditches than for the production of materials for sub-drainage schemes. Difficulties commonly arise in the rapid provision of graded stone, piping, tiles, or improvised channelling. The utmost use should therefore be made of open designs consistent with safety, a policy followed with advantage by the U.S. Aviation Engineers in Mediterranean areas.

#### SECTION 51.—SUB-SOIL DRAINAGE

1. Sub-soil drainage, unless incidental to surface drainage, has seldom been adopted in the construction of military airfields. Facilities and time are too short. Direct measures to improve subsoil or thicken base-course gain ready preference over indirect and speculative alternatives. Further, soil and water characteristics and disposition rarely justify its use. Only soils with a clay content less than 40 per cent., a volumetric change below 30 per cent. and a liquid limit under 40 per cent., can be effectively drained by sub-soil drains.

In certain regions or on some parts of existing airfields it may nevertheless prove the only satisfactory method of maintaining soil stability.

It may be necessary to deal with water percolating through a runway, inadequately sealed or of a gravel type; to intercept sub-surface water percolating from higher ground; to remove water liable to cause damage through frost action; or to lower the water-table of the field.

2. A full scheme of runway subsoil drainage would involve the laying most commonly, of a herring-bone system of concrete or earthenware pipes, butt-ended with  $\frac{1}{4}$ -inch open joint. The top half of the open joint should be covered with a clay "sausage" to prevent infiltration of silt. Pipes, of 6-inch minimum diameter, should be laid at depths of 3 to 4 feet, according to the permeability of the soil. Laterals, 35 to 75 feet apart, would discharge into side-drains, about 5 feet deep, at the runway or shoulder edges.

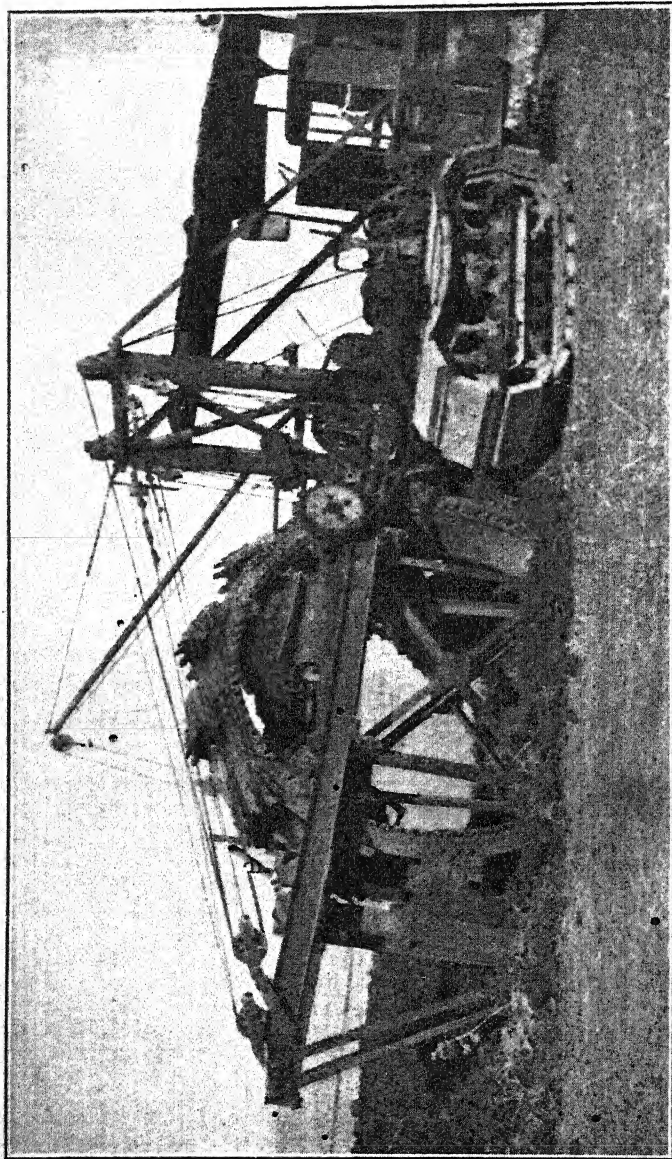


PLATE 13.—BUCKEYE TRENCHER IN COTTON SOIL. SYRIA

- (d) Water is added by means of spray distributors and mixed until colour, texture, and moisture content are uniform. The material will be damp, but not wet or muddy. A ball of it squeezed in the hand should leave the palm moist, but no water should drip from the mixture. On the other hand, a little too much moisture is better than too little.
- (e) The surface is compacted with sheepsfoot rollers, followed by light regrading and the use of pneumatic rollers. Steel broom drags can be usefully employed after shaping.
- (f) For final compaction, smooth rollers are used after a light water spray.
- (g) Surface is kept moist during a normal curing period of 7-12 days.
- (h) If heavy service is required, and time allows, a wearing course of bituminous material,  $1\frac{1}{2}$ -2 inches thick, may be added.

## CHAPTER 15

### MISCELLANEOUS TYPES OF SURFACE

#### SECTION 104.—WOOD LANDING MAT

1. The wood landing mat has been developed, for light or heavy service, where lumber is plentiful. Tests carried out by the Engineer Board, Fort Belvoir, U.S.A. have been so promising as to give assurance of practical success under favourable conditions. Construction represents a heavy task. Such mats should be considered as alternatives for bituminous methods, with stone or sand, rather than as the equivalent of transportable steel tracking.

In some localities, the life of the timber may be short owing to decay or insect pests, and preservative treatment then becomes important.

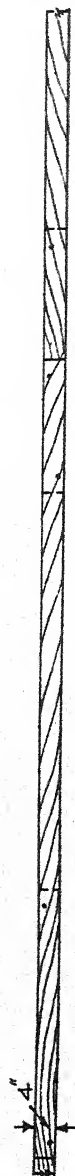
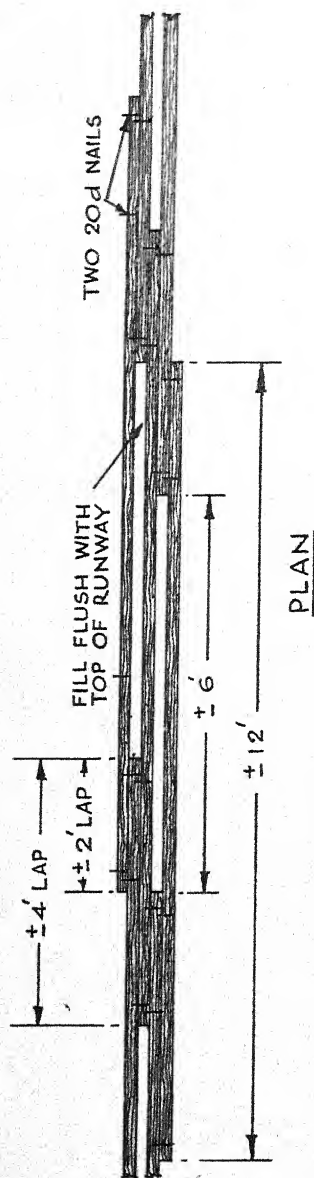
Green, rough lumber is preferred, but dry, dressed timber can also be used. It should be reasonably free from defects, such as knots and dry rot. The best quality will be selected for the central strip. Nails used are 4-inches with rough lumber and  $3\frac{1}{2}$ -inches with dressed. The lumber may be cut, for economy, in varying lengths, 10, 12, 14 or 16 feet. Use of random lengths causes delay in laying. Equal lengths should be assembled for different parts of the runway. Tolerance in cutting should be kept to approximately  $\frac{1}{8}$ -inch in section and 3 inches in length.

2. A wood mat made of 2-inches by 4-inches lumber nailed together with the 4-inch dimension vertical, may be laid in two patterns "block," or "staggered." The former is the easier to construct, the latter is more effective. The form of construction is shown in Plate 49.

3. Quantities involved, for a runway 5,000 feet long by 150 feet wide, are roughly :—

Pieces, 2 inches by 4 inches averaging 12 feet	...	250,000
Quantity in board feet	...	2,000,000
Nails	...	1,178,000

A portable circular saw-mill may be estimated to produce 22,000 board feet per day of 20 hours' running.



DETAIL OF JOINT - 12 FT. MATERIAL.

NOTES.

1. OMIT FILLERS AT SIDE OF RUNWAY AS SHOWN.
2. ADJUST LAYING OF SOLID LAMINATION TO PROVIDE AT LEAST 1-INCH CLEAR DISTANCE BETWEEN ENDS OF PIECES.
3. OPEN SPACES BETWEEN 2x4'S TO BE FILLED WITH SUBGRADE OR WITH MATERIAL EQUALLY OR MORE IMPERVIOUS.
4. DO NOT NAIL ALL OF EDGE FILLER BLOCKS SO SOME CAN BE REMOVED IF MAT DISTORTS DUE TO MOISTURE.
5. 3-FEET OF SOLID LAMINATION TO BE CONSTRUCTED AT ENDS OF RUNWAY ONLY.
6. TIMBER USED IN EACH PATTERN TO BE SAME LENGTH.

PLATE 49.—WOOD LANDING MAT—STAGGERED PATTERN

4. Laying schemes, as for steel mats, can be evolved to provide two, four or eight simultaneous working faces, but generally the production of wooden mats will be the limiting factor. Working parties on each face will be :—

Supervisor ...	...	...	...	...	...	...	1 man
Nailing ...	...	...	...	...	...	...	17 men
Helpers ...	...	...	...	...	...	...	8 men
							—
							26
							—

The speed of laying, under favourable conditions, should be 30–40 square feet per man hour, compared with 100 square feet for pierced steel planks.

5. The finished runway must be free of all loose or projecting nails. As the mat is laid, all open spaces are filled with selected soil material. The fill is compacted and finished off flush with the wood surface. It should be at least as impervious as the base or sub-grade under the mat.

6. The sub-grade base should be prepared as thoroughly as for P.S.P. with maximum permissible transverse slope. No sills or sleepers of any kind are to be used under the wood mat, as they will lead to over-stressing and fracture.

7. In view of the small thickness of the wood landing mat and the probable permeability after considerable use, the quality of base and sub-grade is obviously a factor of first importance.

#### SECTION 105.—CORAL

1. In the Southern Pacific coral has been used, with great success, on well-drained sub-grades, for both base and surface courses carrying the heaviest bomber loads. Coral deposits fall into three main types :—

- (a) Reef.
- (b) Beach.
- (c) Lagoon.

These may exist well above sea level as compact limestones, or as loose or well-cemented deposits near or below sea level. The most suitable type for airfield construction is obtained from reefs and lagoon fills, consisting of a mixture of coral, sand, shells, organic material and limy mud in various proportions. Easily excavated, it has excellent bonding properties. Good quality coral will cement within three to five days.

2. Moisture content must be closely watched. Some grades of coral contain a considerable percentage of clay, and will not compact properly if the moisture content is too high.

3. Where coral has been found 4–8 feet below the surface, the soil has been stripped down to the coral, followed by grading, and compacted with tracked rollers or normal wheeled traffic. The sheepsfoot roller is useless on coral.

Normal practice is to remove 15 inches of soil, and lay a surface course of 18 inches of underwater coral, broken into small angular pieces of about  $\frac{1}{2}$  inch. Where time has permitted, this course has been laid in 8-inch fills compacted to 6 inches. In cases of urgency, the whole depth may be laid at one time, with additional surfacing after settlement. No priming coat or wearing surface is required.

4. Used as a base for a mat surface, 8-12 inches of coral will suffice. For taxi-tracks, a minimum of 8 inches should be used; warm-up areas, 8 inches thick for fighters, 12 inches for bombers.

5. If clean white coral containing no foreign material is used, laying and compaction can be carried out in heavy rain, provided that the drainage system is adequate. For example, one airfield was constructed with pure white coral in the South West Pacific region in eleven days during which 10 inches of rain fell.

6. Drainage is essential to prevent the formation of soft patches especially on all-weather heavy duty airfields.

7. Maintenance is light, but regrading may be occasionally necessary. Repairs are effected with fresh raw material of the proper moisture content. Experience has shown that salt water bonds coral better than fresh water. Best results are obtained if maintenance is carried out after rain, while the coral is still wet. In dry weather, coral runways must be sprinkled to alleviate dust and prevent ravelling. Economy in maintenance and dust control may be obtained by the application of a coat of asphalt emulsion (0.4-0.7 gallon/square yard).

8. P.S.P. has been used with excellent results on coral. If hollows form after service, they are filled through the apertures in the P.S.P.

9. When crushed, screened and washed, the harder forms of coral are suitable for bituminous mixtures, and for concrete aggregate.

#### SECTION 106.—BURNT BRICK RUNWAYS

1. In several regions, notably where "cotton soil" prevails, bricks have been reclaimed or burnt, and used in runway construction with marked success. Normally, this method would only be favoured where a hard pavement is essential, where additional runway height above water level is desirable, and where adequate natural stone or gravel within economic distance, is not available.

2. Rapid run-off should be ensured by maximum camber or cross-fall. Any soft patches in subsoil create cracks and depressions through which surface water will percolate and lead to break-up of the pavement.

3. Examples of runway construction :—

(a) An all-weather fighter airfield, with a runway of 1,250 feet by 50 feet, and dispersal areas for four squadrons, was required during operations in Italy in 1944. The site was on ploughed land with clay subsoil. Materials available were bricks, gravel, and decomposed limestone; later P.S.P. became available.

Ends of runway were constructed with bricks, laid on edge in a herringbone pattern, upon a 2-inch sand underlay. Sand cement was grouted into the interstices and a concrete curb was provided. Sixty bricks were used per square yard.

40,000 bricks, with corresponding sand course, grouting and curb, were laid daily by 30 sappers and 74 native pioneers, using thirty 3-ton lorries. The rate of construction was heavily retarded by shortages of material and transport.

Pilots reported that this brick surface was excellent, comparing well with other forms of surface.

- (b) Locally burnt bricks have been used in Eastern India for the construction of a heavy bomber airfield upon a site of clayey sand. The base course, 6 inches thick, consisted of two layers of bricks, laid flat and the joints filled with sand. Surface course; one layer of first-class bricks on edge (5 inches deep) in 1 : 4 cement mortar. The runways proved capable of withstanding heavy pneumatic-tyred traffic, but could not stand up to local bullock cart traffic with its iron tyres.
- (c) Brick construction for airfields has been economical and effective under the conditions obtaining in Holland. Airfields have been constructed entirely in brick or partly brick and partly concrete, and have the advantage of being easily repaired when necessary.

The Dutch method of construction consists of a single course of bricks on well compacted sand. Vegetable soil has been removed to a depth of 12 to 16 inches, and the excavated area filled with clean sand to a similar depth and thoroughly compacted. Sizes of bricks vary, but the two general sizes are 8 inches by 4 inches by 4 inches, and 8½ inches by 4 inches by 3 inches paviors. Bricks were laid in garden-wall bond or herringbone pattern to a 4-inch thick layer and tamped with wood tampers. Joints were generally filled by laying ½ inch of sand on the brick surface, and brushing with water into the brick joints. A sand cement grout has also been used. A coat of tar has been added to the finished surface, possibly more for camouflage than waterproofing or wearing purposes.

Careful drainage is essential owing to penetration of water through joints and in some cases through the bricks.

#### SECTION 107.—COIR MATTING FOR AIR O.P. RUNWAYS

1. Landing grounds surfaced with coir matting, without steel track, have been used by Air O.P. squadrons in Italy, enabling these light aircraft to be operated in all weathers from otherwise impossibly soft and muddy ground. For this task a strip 150 yards long and 24 feet wide is normally sufficient, though a length of 200 yards is preferable.

2. After grading, two parallel rolls of matting, each 12 feet in width, are laid with a small overlap at the centre. The matting is anchored with standard pickets, driven in flush with the ground, along the sides and centre of the runway. Where joints occur between the rolls of matting, ends are sunk in a trough, filled with a row of sandbags beaten down to surface level. At the ends of the runway, the matting is buried in earth well tamped-down.

Twelve men can lay a track in three hours. Materials represent two 3-ton lorry loads.

3. With daily maintenance, these landing grounds have proved satisfactory for light aircraft, in spite of heavy rain and even when the surface has been covered with flood water.

## SECTION 108.—USE OF OIL ON AIRFIELD SURFACES

1. Oil has been used with considerable success, in the Middle East, for allaying dust on landing lanes, tracks and standings. Both light and heavy oils have been used. The best results were obtained with fuel oil having a small percentage of wax content.

An average of three to four dressings of heavy oil produces good results. With lighter oils, many more applications may be necessary.

A well-graded soil is required for satisfactory results.

2. Under the climatic conditions of Iraq, satisfactory all-weather surfaces capable of heavy loads have been constructed by using crude oil on alluvial river or clay silt loam (normal clay content over 10 per cent.). The winter rains had little effect on airfields thus treated, provided that no wheeled traffic of any sort was permitted on the surface while wet. Careful inspection of runways after rain was necessary. Any oil washed away had to be re-applied as soon as the surface was dry.

Camel thorn had to be kept in check, to prevent runways from breaking up. Oiled runway surfaces should be completely re-oiled annually, as part of normal maintenance. Finally, surface conditions approximate those obtaining upon a runway with a thin course of sand-bitumen mix.

3. In Palestine and Egypt soils of a loamy nature have been given dressings of oil, gradually reduced from 0.7 gallon per square yard for the first application, to 0.25 gallon per square yard for the fourth dressing.

Best results were obtained when the formation was rolled before each application. The use of a lighter oil for the first dressing, or even the saturation of the ground with water, increased penetration, and improved results.

Repeated rolling with a pneumatic roller proved especially beneficial.

Good results were observed on a loose soil after three dressings of "tank bottoms," containing a high percentage of paraffin wax. The surface tended to be greasy during and after rain.

4. Owing to the incidence of monsoon rains, oil has been used in India only as a temporary dry-season dust palliative. Locally refined light oils have been used experimentally :—

(a) Jute batching oil.

(b) Jute batching oil plus 10 per cent. refinery residual asphalt (tended to filter out).

(c) Jute batching oil plus 10 per cent. refinery residual asphalt plus kerosene (tended to filter out).

(d) Jute batching oil plus 15 per cent. refinery residual asphalt.

The last mix displayed the best binding qualities.

Normal practice is as follows :—

Scarify, grade and roll surface. Apply oil, 0.25 gallon per square yard. Dressing applied every two to four weeks, as necessary, and when soil has dried out after heavy rain.

Oiling has also been applied to a base-course under pierced steel planking, at 0.75 gallon per square yard. The base was silty loam, mechanically stabilized. Satisfactory two months after laying, except for local failures due to poor surface drainage.

5. Trials have been carried out to determine the most suitable type of oil for dust alleviation on the clayey types of soil commonly prevailing in N.W. Europe. Lacking imports, waste or sump oil may be used. Owing to supply restrictions treatment will generally be limited to take-off points, marshalling areas and hardstandings.

Emulsified bitumen, in a diluted form, has been tried under Sommerfeld track, light Bar and Rod and P.S.P., with satisfactory results. The surface is first sprinkled with two applications of water,  $\frac{1}{2}$  gallon per square yard, and allowed to penetrate. The emulsified bitumen is mixed, first at 250 gallons of emulsion to 580 gallons of water, in a bituminous distributor, and one coat is applied at the rate of  $\frac{1}{4}$  gallon per square yard. The area is then trammelled sufficiently to break up the skin surface and allow penetration. A more dilute mix at 3 parts water to 1 part of emulsion, is then used in four applications at 15-minute intervals. The surface is very lightly dragged after each application to allow further penetration.

The aim is to effect a uniform penetration of  $\frac{1}{4}$  inch depth, giving a tough crust with a thin surface skin of asphalt.

For a 1,200-yard fighter airfield, with 3,000 yards of taxi-track and 54 hardstandings, covered at 0.42 gallon of emulsion per square yard, 232 tons of emulsion and 1,246 tons of water are required.

6. In all cases, the requisite quantity of oil or emulsion most suitable for any particular type of soil must be determined by practical tests.

#### SECTION 109.—SALT AND BRINE FOR DUST ALLAYING

1. Soil stability, resulting in an abatement of the dust menace, has been successfully effected and retained on arid airfields by the use of magnesium chloride brine produced by the evaporation of sea water. Favourable opportunities for use have arisen most frequently close to the Mediterranean sea-board, where summer-dry conditions create urgent demands for dust control and where, on the other hand, facilities for obtaining or producing brine are favourable owing to heavy seasonal evaporation. The method could rarely be adopted with success in regions of evenly distributed rainfall.

2. The sprinkling of calcium chloride or magnesium chloride flakes, as practised for dust-allaying on continental roads in peace-time, would rarely be justified on airfields under operational conditions, but the possible benefits must not be ignored. Good results might be obtained by the use of 100 tons of the flakes upon selected areas of 100,000 square yards, on suitable soil, and at certain favourable times of the year, at which times the need is likely to be most urgent.

However applied, the hygroscopic salt has the property of drawing moisture from the air and liquefying into a calcium chloride solution, which permeates the top of the soil and acts as a moderately stable binder, until washed out by rains.

3. Mediterranean sea water has the following composition :—

				Density—3.5 deg. Beaume	
				Per cent. by weight	lb. per gallon
Sodium chloride	...	...	...	2.90	0.20
Hydrated magnesium chloride	...	...	...	0.69	0.05
Magnesium sulphate	...	...	...	0.23	0.02
Calcium sulphate	...	...	...	0.17	0.01

Evaporation is effected in artificial or natural beds, until saturation point is reached at 25 degrees Beaume. At this point, suspended matter and calcium sulphate are deposited. Finally, there is crystallization of sodium chloride at 30 degrees Beaume, when equilibrium is reached by the magnesium chloride in the "mother liquor," which absorbs about as much moisture from the atmosphere as it loses in evaporation.

At 25 degrees Beaume, 40,000 gallons or at 28 degrees Beaume, 20,000 gallons of brine would contain 10 short tons of hydrated magnesium chloride.

4. An example of successful work on a bomber airfield in North Africa, with brine at 26 degrees Beaume or 1.22 sp. gr., may be cited. In this case, the fine clayey sand did not allow adequate penetration in a natural state. The surface was scarified by motor grader to a depth of approximately 6 inches. Two gallons of brine per square yard were then applied by truck-mounted distributors, followed by sheepfoot rolling to maximum compaction.

The surface was then lightly harrowed to a depth of 3-4 inches, given a second application of 2 gallons of brine per square yard, followed by the sheepfoot roller. This was repeated, raising the total application of brine to 6 gallons per square yard. After a final grading by motor-graders, another gallon of brine was applied, before the surface layers were compacted by rubber-tyred rollers.

The total of 7 gallons contained 7 lb. or 8 lb. of useful salts, a heavy dosage, applied with exceptional thoroughness. Results were highly successful. In many cases, adequate results could be obtained, by simple penetration methods, with 3 or 4 gallons of brine per square yard.

5. Brine has a very deleterious effect on mechanical equipment. Tanks, pumps, valves, truck springs and brakes suffer badly from corrosion. In addition, pumps tend to become clogged, owing to the precipitation of sodium chloride or gypsum crystals. This latter condition can be partly overcome by injecting a  $\frac{3}{4}$ -inch stream of unconcentrated sea-water at the pump intake and by shutting down the pump daily and circulating fresh water through the unit. The corrosive effect on exposed metal parts of the trucks can be combated by washing frequently with a pressure spray of fresh water and heavily coating with oil.

The corrosive effects of different salts is frequently discussed, in relation to the question of ill-effects upon the internal engine parts of aircraft using an airfield stabilized by this method. Some harm undoubtedly is done, but it can be reasonably assumed that the reduction in engine life, resulting from a big quantity of dust from the untreated surface, would be a far more serious factor than any ill-effects attributable to the salt content of the comparatively small quantity of soil sucked in from a well stabilized surface.

#### SECTION 110.—CHEMICALS FOR WATERPROOFING SURFACES

1. Experiments have been undertaken in England and America to test the efficacy of various chemical products as waterproofing agents, when mixed with natural soils before compaction. The function of the chemicals is not to bind the surface, but simply to maintain the water content at a low level during spells of wet weather and thereby to lengthen the period of serviceability upon advanced landing grounds for light aircraft.

Results comparable with those obtained by a bitumen mix have not been envisaged. The aim has been to attain a useful standard of "all-weather" efficiency, by the employment of a very small quantity of imported material. If the soil conditions are favourable for a resinous product, 30 tons of it may be sufficient to treat a landing lane, 1,200 yards by 50 yards. Satisfactory results have been obtained on sandy clay soils with "Vinsol" resin, while "321" resin is suitable only for acid soils. Sodium rosinate and aluminium sulphate have also been tried upon favourable soils.

2. In the U.S.A., a taxi-track surface of sandy clay soil, mixed with "Vinsol" resin, is reported to have proved satisfactory. The soil was pulverized to a depth of 6 inches and thoroughly mixed with "Vinsol" resin, at the rate of 1.5 lb. per square yard. A solution of water and caustic soda (17 lb. soda to 100 lb. of "Vinsol") was sprayed over the mixture and mixed until the moisture content was at its optimum. After shaping, the base was compacted with pneumatic tyred rollers until the tyres no longer made appreciable tracks. The surface was lightly graded and sprinkled, then finally compacted with the pneumatic roller.

3. "321" resin has been applied to stabilized soil surfaces in the same manner. Trials have shown that the pulverized material should be mixed to a depth of 4-6 inches for light bombers and fighters. For heavier aircraft, mixing should be carried out in two courses to a depth of 10 inches, using over 1 lb. of "321" resin per square yard. Sea water may be used for sprinkling the surface before using "321" resin, without any appreciable deleterious effect upon its waterproofing qualities.

In arid climates, the surface should be primed with oil at the rate of 0.2-0.3 gallons per square yard, to prevent rapid drying out and consequent erosion and dustiness.

4. Experimental treatment with sodium rosinate and aluminium sulphate has been less promising. Surfaces have been thereby improved to some extent, but it is doubtful whether they could withstand much aircraft traffic after rain. These two products are unsuitable for soils with a high clay or silt content.

5. The inducement to proceed with experiments in the use of chemical agents has declined since the development of bitumenized hessian. P.B.S. can be employed with assured success for allaying dust and protecting the surface against deterioration by surface waters, upon any type of soil that is strong enough when dry to bear the aircraft load. Against so secure and wide a range of serviceability speculative half measures can have little appeal.

#### SECTION 111.—PAVED SEAPLANE SLIPWAYS

1. A slipway differs from an airfield runway in that it is partly submerged in water. Underwater construction may be performed either by coffer-damming and unwatering the site, or by lowering precast concrete slabs.

2. An example of the second, more simple method is as follows: A fill was graded with a tractor equipped with a 30-foot bulldozer extension that permitted a screed to operate right to the end of the fill, while keeping the tractor within shallow water. Concrete slabs, 12 feet by 12 feet by 6 inches thick, with interlocking joints, were placed by a crawler-mounted derrick operating along a temporary trestle.

3. A third method, the recently devised "intrusion" or cementation method, consists of pumping a special grout under high pressure into

the voids of graded stone aggregate. The grout, which is not affected by sea water, fills the voids in the stone producing a monolithic mass below a timber mat used as a top form.

4. The slipways can also be built on the shore, in an excavation from which the tide would be kept from entering until the slipway was completed.

5. Seaplane ramps in places subject to wide tidal ranges have been constructed by using pre-cast beams and slabs, which can be rapidly placed on previously driven piles. The beams are of "H" section, 30 feet long, providing grooves down which slabs, 15 feet square and 10 inches thick, can slide to form the deck. Ramps have commonly been given a gradient of 1 in 10 to 1 in 14, with a total width of 50 feet-100 feet.

## CHAPTER 16

### AIRFIELD CONSTRUCTION PRACTICE IN INDIA

#### SECTION 112.—GENERAL

1. Airfield construction in India displays a wide variation of method owing to the different climatic and geological conditions prevailing throughout the country. Specifications are governed by local resources. Construction in concrete is often impracticable on account of water shortage. Burnt bricks are widely used where no stone for quarrying is found.

2. Shortages of equipment and transport have commonly, in the past, influenced both method and design.

#### SECTION 113.—EXAMPLES OF AIRFIELD CONSTRUCTION

1. Examples of airfield construction are given in illustration of methods adopted, in different regions, under Army or P.W.D. control.

2. **Baluchistan.**—Fighter airfield in hilly country at elevation of 5,000 feet. Rainfall, 6-8 inches a year. Temperature range, 10-100 degrees F. in the shade. Soil, clayey sand ("S.F."), compacted with steam-rollers into a suitable sub-grade. Owing to shortage of rollers, the original runway specification was changed from macadam to "Colcrete" slabs, 4-5 inches thick, with a base course of broken stone, 4½ inches thick before consolidation. Size of bays was 50 feet by 18 feet 9 inches, and 18 feet 9 inches by 18 feet 9 inches alternately, with butt joints. Drainage was by means of earth drains, 1 foot wide 2 feet 3 inches deep, boulder-filled, leading to open drains.

3. **Sind.**—Heavy bomber airfield, on fairly level ground in a district having an annual rainfall of 29 inches, and a maximum temperature of 127 degrees in the shade. The soil was of a clayey type, containing about 10 per cent. of sodium salts, which have a deleterious effect on bitumen in cold weather. To keep down the salts, a 6-inch layer of clean sand was placed on the foundation. The runway consisted of 4-inch thick 1:2:4 cement concrete, on a course of 6-inch or 4½-inch thick bricks, on edge, embedded in the sand. The side strips of the runway were stabilized by the addition of sand, and finished to a gradient of 1 in 200. Cross-fall carries rainwater to open drains.

4. **Punjab.**—Heavy bomber airfield, on a flat cultivated plain, about 600 feet above sea level. Rainfall is 15 inches per annum. The sub-grade, a clayey soil of medium plasticity, was compacted by sheep-foot and road rollers. Stone, cement, and coal for brick-burning were available locally. Runway consisted of 4-inch thickness of 1:2:4 cement concrete, laid on waterproof paper, and the taxi-track of bricks

on edge, in 1:5 cement mortar, covered with  $\frac{1}{2}$ -inch— $\frac{1}{2}$ -inch thick 1:5 cement plaster. French drains led to soakage pits.

**5. United Provinces.**—Fighter airfield on soil of "S.F." classification. Annual rainfall, 40 inches. Runway was constructed in three layers, on natural surface. Bottom layer, 3 inches flat bricks or  $4\frac{1}{2}$  inches of 3-inch nodular limestone, compacted to 3 inches. Intermediate course,  $4\frac{1}{2}$ -inch nodular limestone, graded  $\frac{3}{4}$ -inch to  $2\frac{1}{2}$ -inch gauge and consolidated to 3 inches. Surface course, 1:2:4 cement, in concrete slab. Transverse expansion joints were 50 feet apart, longitudinal construction joints  $12\frac{1}{2}$  feet apart, and longitudinal expansion joints  $37\frac{1}{2}$  feet apart. Expansion joints  $\frac{3}{4}$  inch wide. Natural drainage, run-off from edge of runway being taken by earthen gullies to natural drains.

Another example of runway construction in this province is that of a heavy bomber airfield, which has been extensively used by heavy transport aircraft; 6 inches of block stone soling, under  $4\frac{1}{2}$  inches macadam consolidated to 3 inches, sprayed with three coats of road tar. Surface chipping used a total of 10 gallons tar and 6 cubic feet of chips per 100 square feet. Owing to the flatness of the site, a satisfactory outfall for the French drains was not obtained and water-logging under edges of runways followed rainy periods. After heavy use, runways and taxi-tracks tended to become "bumpy." It was considered that 3-inches to 4-inches of broken stone would have been more suitable than the stone pitching.

**6. Madras.**—Average rainfall of 38 inches. Light bomber airfield on a well-graded gravel-sand-clay mixture to the following specifications: 6 inches stone soling and a subgrade of  $2\frac{1}{2}$  inches metalling (2-inch gauge), blinded with 1-inch gravel. Surface course,  $4\frac{1}{2}$  inches of 1:2 $\frac{1}{2}$ :5 cement concrete slab, using graded aggregate of two parts  $1\frac{1}{2}$ -inch size to one part  $\frac{3}{4}$ -inch. Drainage was by means of open drains on edge of each strip.

**7. Central Province.**—Light bomber airfield, where there are natural slopes up to 1:30, and an average rainfall of 50 inches between June and September. Runways have been sited on minor ridges of uncultivated ground, sloping down to rice fields on either side. Soil, partly well-graded sand-clay mixture, partly moorum (decomposed rock, 10–20 per cent. clay), and graded particles up to 3 centimetres diameter. Construction had to be undertaken urgently, labour was short, and the quarries might become flooded during the monsoon. Runways were constructed to two specifications. In the first case, 6 inches cement-stabilized moorum (12 per cent. cement by weight), surface dressed with bitumen and  $\frac{3}{4}$ -inch chippings and then with  $\frac{3}{4}$ -inch pre-coated chippings. The other specification was 5 inches stabilized moorum (10 per cent. by weight) covered with 1 inch– $1\frac{1}{2}$  inches of 1:2:4 concrete. Taxitracks were  $4\frac{1}{2}$  inches water-bound macadam on hard core as required—surface dressed with bitumen or tar, and blinded with  $\frac{3}{4}$ -inch chippings.

**8. Bengal.**—An airfield, where annual rainfall averages 66 inches, has been constructed, using 6-inch thick 1:2 $\frac{1}{2}$ :5 cement concrete over 3 inches laterite soling, on a subgrade of hard laterite soil varying from rock to particles like coarse gravel containing some clay. No expansion joints were provided, but these were subsequently found to be necessary.

Another airfield for medium bombers has been built, on sandy type subgrade, to a specification of 6 inches 1:2 $\frac{1}{2}$ :5 cement concrete and  $1\frac{1}{2}$ -inch stone ballast, over a double layer of brick soling. Bricks were made locally. No satisfactory supply of local stone. This airfield has been in use for two years.

9. **Assam.**—Examples of light, unreinforced concrete slab construction, on a favourable site, for heavy bombers.

- (a) A flat, well-drained site on typical Assam tea-garden land. Soil, sandy loam. Rainfall, 100 inches, mostly between mid-May and mid-October. Winter months cool and dry.

Original specification : 8 inches soling and 4 inches concrete (1 : 3 : 5) in 18-feet squares. Upon further experience of soil this was cut to 6 inches of hand-rolled shingle for base-course, with 4 inches concrete pavement (1 : 2 : 4) for runway and taxi-tracks. The stronger mix was specified because of the dangers of bad mixing during the monsoon, apart from the requirements of the lesser thickness. Aggregate was clean, good quality crushed stone. All materials were transported from distant sources.

Heavy rainfall tended to undercut the edges of the concrete, especially along taxi-tracks, with resultant cracking under load. A concrete haunch 8 inches by 8 inches was added.

All work on formation was by scrapers and motor-graders.

- (b) Another example is that of an unfavourable heavy bomber site, on loamy soil, with some patches of "cotton soil". A bad site on uneven tea-garden ground. Formation by hand labour.

Runway specification : 10 inches of hand-packed soling with a 4-inch (unconsolidated) thickness of bitumen-grouted stone. Hardstandings and turning circles, 6 inches soling and 4 inches of concrete, while the taxi-tracks are partly the same as the runway, and partly 6 inches of consolidated shingle, with 4 inches of grouted stone pavement.

In spite of the heavy soling and extensive system of French and open drains, maintenance proved heavy. Depressions occurred causing cracks to surface. Patches are repaired with bitumen macadam or bitumen-sand mix carpet.

10. **Arakan.**—The construction of durable airfields is particularly difficult. The topographical and climatic conditions of Arakan, together with a shortage of good local materials, have proved generally adverse factors. P.S.P. and Sommerfeld track have been available for operational service.

The type of country is paddy, surrounded by low jungle-covered hills. Rainfall, 150 inches between June and October; temperature between 50 degrees and 100 degrees F.

- (a) An airfield for fighters and light bombers has been constructed on a sandy spit, approximately 600 yards wide. Owing to the impossibility of compacting the natural surface, Sommerfeld track was laid over a double diagonal mat of 1-inch to 2-inch bamboos, and strained back to buried log anchorages. Open drainage led to natural drains and tidal cuts. This airfield proved more satisfactory during the monsoon period than was expected.

- (b) Another site on clayey sand was used by transport aircraft. Sub-grade compacted by water and tamping rollers. Runway was constructed in three layers. First, a coat of "Nairobi II Bithess" (bituminized hessian) sprayed with 80/100 bitumen at one-third gallon to 1 square yard and sanded. Second coat, 1½ inches consolidated bitumen-sand mixed in Barber-Greene mixer with 9 per cent. by volume 80/100 bitumen. Finally, P.S.P. laid on top and rolled in. This method of construction proved satisfactory, and gave promise of considerable durability during the monsoon period.

## CHAPTER 17

## ROAD AND AIRFIELD CONSTRUCTION PRACTICE

## SECTION 114—GENERAL

1. The principles and practice of airfield construction and development, in comparison with road engineering, are frequently discussed.

An analysis of different features is not of mere academic interest. Both works have much technical literature in common and experience gained in one branch will be frequently utilized for guidance in the other.

2. Individually, the methods of work, organization and planning adopted in airfield engineering differ little from those in road construction. Collectively, the differences become important, apart from the influence of administrative factors involved in the direct service of air force units in the field.

## SECTION 115.—COMPARISON OF ROAD AND AIRFIELD CONSTRUCTION

1. Outstanding features of military airfield planning and construction for comparison are :—

- (a) An airfield is a heavily concentrated and comparatively uniform engineering task. Work is commonly undisturbed and is of such volume as to permit of the most effective use of central plant. Abnormal standards of speed and efficiency are consequently demanded and obtained.
- (b) Reconnaissance and laying out demand sound knowledge of the characteristics of different aircraft types and of air force technical requirements in general. Disposition of dispersals, services, clearances, camps, control towers, and administrative buildings is a special problem.
- (c) Aircraft are much more difficult to control on the ground than vehicles, and their safety is more directly threatened by physical factors, including wind, rain, visibility and dust. An engineer is expected to take measures to minimize all landing disabilities and must study all relative conditions in order to do so effectively and economically.

Dust on roads is merely a nuisance ; on airfields it may reduce serviceability to nil or cut down engine life to a dangerous and excessively uneconomical degree.

- (d) There is much less latitude in the selection of a serviceable airfield than in the alignment of a new road, because of the severe gradient limitations and the objections to heavy cut and fill over the wide area involved.
- (e) In developed countries road engineers will usually benefit from the preliminary guidance of a network of roads and tracks and from the direct evidence of long service.
- (f) Like a bridge, a runway must be finished to give any service at all ; hence the peculiar urgency and responsibility of an accurate estimate of completion dates.

- (g) On airfields, normally, wheel-loads are heavier and tyre pressures higher, but road engineers have to deal with a wider range of service, including heavy tracked vehicles, and to provide for more intensive traffic. Road service is uniform. Different parts of an airfield are subjected to totally different standards of loading and abrasive action.
- (h) Camber and cross-fall gradients are severely low, to avoid serious accidents due to side-slip. Risk of strain to the under-carriages of aircraft merits more consideration than it commonly receives.
- (i) Depressions in wide, non-rigid runways collecting water and threatening sub-grade stability are characteristic and almost inevitable. Efficient run-off from road surfaces is less important and is easier to ensure.
- (j) Heavy run-off from a wide runway involves the rapid collection and disposal of storm water, for the collection of which an open drain alongside the tracked area cannot be used with safety.
- (k) Area drainage, which may involve the lowering of the water-table, is a bigger and more critical task. Flooding is more serious. Relatively more airfield failures, due to inadequate drainage measures, are on record than road failures.
- (l) A small depth of standing water which would merely slow down road traffic, may render a runway seriously dangerous, or wholly unserviceable.
- (m) Runway surfacing does not get the benefit of traffic compaction like a road. It is subjected to heavy abrasion by stationary wheels on touching down, and to distortion upon sharp turning of aircraft at the end of the run.
- (n) Punctures have much more serious consequences upon airfields than roads.
- (o) Surface faults and deterioration, often capable of anticipation by responsible engineers, are a factor in the causation of accidents. Ground accident prevention and removal of surface defects are more directly an engineer's constant responsibility on airfields than on roads. Harm done to engine parts by dust, and to propellers by grit or chippings, must be assessed and, if serious, alleviated.
- (p) A large developed airfield may represent 30 or 40 miles of a main road. Over such a distance, the road engineer may frequently vary his specification on account of changing sub-grade or adjacent resources. The airfield engineer may have to scheme out different surfacing specifications, in the one centre of activity, for (1) runway ends, (2) middle section of runway, (3) hard-standings, (4) taxi-tracks, and (5) perimeter and access roads.
- (q) Camouflage and marking problems belong almost exclusively to the airfield engineer and are subject to frequent change of policy, in relation to the tactical situation and physical conditions.
- (r) Methods of demolition and repair will commonly differ, owing to absence upon airfields of vulnerable bridges, hill-side tracks and embankments. Filling of runway craters has to be done more meticulously owing to greater risk of accident, if any subsidence occurs.

- (s) Finally, the airfield engineer, particularly in war, is more concerned with the human factor. He is in constant touch with a single user command. Confidence must be gained. Pilots should "like" their airfield and appreciate the practical efforts constantly being made to reduce the danger risk, or increase the efficiency of dispersal, circulation and runway service. Wasteful projects should be discouraged; sound improvements should be anticipated before the call is made. In practice, work is rarely finished upon an operational airfield until it is abandoned.

2. The work of the road engineer is more impersonal; he serves the forces as a whole. Maintenance is commonly a self-evident and circumscribed task.

## CHAPTER 18

### AIRFIELD CONSTRUCTION DURING OFFENSIVE OPERATIONS

#### SECTION 116.—GENERAL

1. Conditions prevailing during the invasion battle are marked by special features, which merit consideration as a whole. Heavy restrictions are placed inevitably upon the movement of mechanical equipment, so that the highest standard of efficiency is demanded from operators to ensure good treatment of plant and maximum output. Comparatively few men of high skill are required but these must be completely familiar with every aspect of their work. The call for utmost speed in landing ground construction is insistent and the results of successful achievement will often be spectacular.

There is exceptional need for thorough military training of all airfield troops, in combined operations and in ground defences.

2. During the early stages of a sea-borne invasion, the highest priority is given to the task of establishing a few advanced landing grounds in the shortest possible time. Once an adequate beach-head has been secured and an advance continues, the maintenance of road communications will assume higher importance, until a balance is regained and the ground and air requirements become equally important.

3. Theoretically, landing ground construction during an advance is an intermittent activity. In practice, there is no cessation of work, even in a temporarily static situation, for standards are never high enough and the call for new or alternative sites is unceasing and urgent.

4. The variety of tasks performed is illustrated by the following record, from Sicily, of 17 days' work, in fine weather, for one Airfield Construction Group, R.E. :—

- (a) Construction of one bomber airfield, which involved the grading and consolidating of a surface area of 1,000,000 square yards.
- (b) Construction of three fighter-bomber airfields, each 600,000 square yards.

- (c) Restoration of an enemy permanent airfield, including removal of wreckage, dangerous buildings, mines, repair of cratered concrete runway and taxi-tracks, and extension of dispersal facilities.
- (d) Maintenance of three active airfields, including repair after bombing.

The soil was hard baked clay, of "cotton soil" type, and the cultivation mostly stubble, with a little plough. Some thousands of yards of piped ditches and culverts were provided.

#### SECTION 117.—FIRST REQUIREMENTS ON LANDING

1. Questions of equipment and organization are governed by special circumstances, in every operation, but the lessons of Sicily and Italy will be recorded to illustrate the problems. In addition to reconnaissance parties, a small number of sappers and tipping lorries are wanted early. Tools should include picks, shovels, matchets, stone-forks, 14-lb. sledge hammers, felling axes, and hand earth-rammers. The following are also needed: mine detectors, R.A.F. ground strips, banderols, plain wire for pulling out mines, rubber-tyred wheel-barrows and explosives.

2. The question of exactly when to land the mechanical equipment has always proved difficult. Graders, rollers, scrapers and angle-dozers are soon urgently needed, but risk of landing losses must be cut to a minimum with such irreplaceable items of plant.

#### SECTION 118.—ENEMY AIRFIELDS

1. Enemy airfields of permanent type have proved to be well made and are commonly provided with good drainage systems. On the other hand, their natural-surface landing grounds have been found, almost invariably, to be too rough and dangerous to be acceptable to the R.A.F. These always require a lot of work to bring them up to proper standard. Little mechanical equipment has been used by the enemy upon surfacing.

Enemy slackness in this direction is not readily explained by differences in air-frame design, in strength of tyres or in discipline. His ground losses have been heavy. Replacement of aircraft may, at certain times, have been comparatively easy, but his repair and salvage facilities have been consistently inferior to our own in the field.

2. Paved enemy runways are commonly shorter but wider than ours. Concrete 6 inches thick, on 12 inches of hand-pitched stone is a typical specification.

3. Airfield obstruction by the enemy has been varied in method and efficiency—ploughing, cratering, laying of mines, and placing heavy obstacles in the landing strips being variously adopted.

The obstruction of the surface is generally undertaken with less thoroughness and system than the more profitable demolition of buildings and equipment.

## SECTION 119.—INSTANCES OF OBSTRUCTION

1. **Ploughing.**—An objective in one assault-landing in Sicily was an old enemy airfield, which had been ploughed up about one month before the invasion. This ploughing was over the whole field, 18 inches deep, and the summer sun had baked the clay furrows. The field was operational, on an emergency basis, in two days, in spite of one day's delay in getting the mechanical equipment ashore.

In other cases (LIBYA COAST), ploughing and laying of mines were skilfully combined and the construction of new airfields elsewhere resulted in a saving of time and better operational results.

2. **Cratering natural landing surfaces.**—On other airfields 50 kg. and 250 kg. bombs had been dug into the ground and fired electrically. Many had failed to explode owing to faulty priming. In addition, wrecked aircraft, petrol-tank wagons, heavy lorries, steam rollers, cars, etc., were scattered about the field. Delays effected were not very serious. To quote three instances :—

- (a) Speed was essential. A landing lane, 1,000 yards long by 50 yards wide was produced, in six hours by 150 men using one roller, two bulldozers and six 3-ton tippers. This work was done under enemy observation, with slight interference.
- (b) Speed of work was less important because extreme road congestion temporarily delayed occupation. Eight craters were filled with hardcore and four large wrecks were removed, without mechanical plant, by 13 men in two days. One 3-ton lorry and hand tools only were used.
- (c) A concrete runway, 1,300 yards by 63 yards, had been obstructed by 27 craters, 15 feet in diameter and 4 feet deep, and five heavy charges had been blown in the side drains. Normally these craters would be filled hastily with hardcore and fines, tamped and rolled, but decision was made to relay the 6-inch concrete pavement, equal to 2,500 square yards. The runway was operational in ten days.

## SECTION 120.—MISCELLANEOUS

1. Two items of special plant required, particularly during offensive operations, are mobile cranes and mechanical road-sweepers, of municipal type.

2. Jeeps are invaluable for field engineers.

3. The L.A.D., which is invaluable, should be equipped with electric welding plant.

4. The assistance of a bomb disposal officer is essential.

5. Hard and fast rules for airfield construction should never be laid down. There is no such thing as a "normal" task; variations are infinite. But the sound instinct necessary for rapid achievement must be based on thorough training and varied experience.

## CHAPTER 19

## PREVENTION OF AIRFIELD ACCIDENTS

## SECTION 121.—GENERAL

1. One of the most urgent reasons for close contact between airfield engineers and the air formations served is to ensure that the utmost is done—by foreseeing risks or by quick interpretation of conditions as they arise—to cut down the accident rate upon the ground. If engineers merely wait for orders and do not anticipate the incidence of adverse factors, capable of improvement, they neglect an opportunity to render important service in the saving of life and aircraft.

2. Under operational conditions, accidents are particularly frequent. There is the haste of a "scramble take-off", and the return of damaged machines, of weary or wounded pilots. Risks due to bad visibility have to be accepted. Every aid in improved marking and surfacing should be schemed out and applied, often beyond the demands of official "standards" evolved for general application.

3. The pilot must always be given the benefit of the doubt. Air commands are habitually reluctant to call for work to be done on precautionary measures appearing to reflect upon the efficiency of pilots or to suggest undue anxiety about risks which are, considered academically, so largely "avoidable." And most precautions are a matter of degree rather than of clear prescription.

4. Of the many accidents recorded by forward based squadrons, which represent a heavy factor of loss, 70 per cent. are normally of airfield occurrence. The big majority of these are accidents upon landing. Accidents on taking off and taxi-ing account together for about one-third. And even some of the landing accidents may be attributable to take-off conditions, as, for instance, when tyres are damaged by stones, metal fragments, or torn tracking, resulting in a flat tyre on touching down.

5. "Airfield standards" are formulated by the Air Force primarily for the purpose of ensuring efficiency and safety upon the ground. In the following sections, the situation is considered in the light of the many accidents which do nevertheless occur. When in doubt as to any action to be taken, the Airfield Commander or Flying Control Officer should be consulted if either is available.

## SECTION 122.—ALLEVIATION OF DUST

The most frequent and urgent call for improvement, upon operational airfields in dry seasons, relates to the allaying of dust, particularly in the vicinity of take-off, assembly and dispersal areas. Measures include watering, oiling, turfing, application of salts, laying coir matting under steel mats and rolling in stone or gravel. Strict traffic control and preservation of an original surface to maximum degree, are fundamental demands. (A summary of the methods of alleviating dust on airfields is given in Appendix X.)

## SECTION 123.—IDENTIFICATION AND MARKING OF AIRFIELDS

1. Easy location of site from the air will often take priority over the risk of enemy attack. Dispersal of aircraft is the only satisfactory protection against bombing, in nearly every case. An airfield should be capable of being spotted and identified from a distance of some miles. Petrol is often too low after engagements to provide for unnecessary diversions.

2. Identification will be assisted by the provision of "airfield identification characteristics" consisting of a two-letter code painted white on a black background or marked out in chalk or by white strips. Each letter should be 20 feet by 12 feet, the combination being orientated so that it is read from the flying control tower or vehicle or from the south. The code may be obtained from the Flying Control Officer of the R.A.F. formation concerned.

3. It is important that corner markings be clearly visible, even in poor light. Arms of stone or strips or boards, painted white, and constructed so as not to form any obstruction, are favoured. Beacons at corner points, clearly visible from a height of 10 feet should be, preferably, of collapsible type. If the side of a landing strip is out of action, for any period of time, side markings must be brought in correspondingly. Time and again, conspicuous corner beacons have made the difference between a good landing and a crash.

4. Side markings must be capable of being run or taxied over without any risk.

## SECTION 124.—AIDS TO JUDGING HEIGHT

On many natural surfaces, pilots have difficulty in judging their height before touching down, notably on mud flats, virgin snow or smooth water. Some detail is required, such as wheel tracks on sand or ripples and floating paper on water. When sandy surfaces have been used considerably, the disability commonly disappears. For fresh surfaces or where the ground does not readily scar, 4-gallon petrol tins or flagged stakes may be lined along the strip with advantage. If flagged stakes are used they must be made of material light enough not to cause damage to an aircraft should they be struck by it. They should not be higher than 4 feet.

## SECTION 125.—OVER-RUN AND CLEARED ZONES

The importance of long extensions, at each end, as a safety factor to provide for over-run or under-shoot, is often emphasized and rarely overstated. It is rarely possible to provide a compacted surface far beyond the strip proper, but the cleared zone should be free of any obstruction liable to pull up an aircraft to a dead stop, and should allow an aircraft to make a "belly-landing" if the engines cut during take-off. The prepared over-run or under-shoot should be firm enough for a normal landing and should, if the conditions permit, extend for 300 yards beyond each end of the landing strip proper.

### SECTION 126.—SOFT PATCHES

1. Soft patches in temporary strips are a common menace. They deteriorate almost imperceptibly, and their full danger may not be disclosed until an accident occurs. The determination of this risk is a heavy responsibility. Over-cautious marking off of suspect patches may seriously reduce the utility of a landing area and introduce other elements of danger. Engineer officers must develop an expert knowledge of surface conditions and of the drag liable to tip on to its nose an aircraft of the type concerned. In the case of fighter aircraft this accident is very liable to occur.

2. Soft patches will be clearly marked for detection from the air and ground, by white crosses and flags, but expert anticipation should minimize soft patches becoming dangerous.

### SECTION 127.—STANDING WATER

This obvious danger is a cause of minor accidents. A certain amount of water will put a strip out of action—a depth of 2 inches is about the maximum permissible for Spitfires, for instance. Water also causes "blinding" of pilots and damage to flaps. Too much camber, to effect quick run-off of water during rain, introduces other risks, making it difficult for pilots to keep straight. Too little camber or a flat surface produces inevitable pools, not only of direct danger but resulting often in the formation of soft patches by percolation to the sub-soil. Aircraft are turned over only above a certain speed, so that water on taxi-tracks is comparatively unimportant.

### SECTION 128.—DRAINS

Open drains, outside the aprons, are so manifestly dangerous, unless of the invisible saucer type, that warnings are unnecessary. But pipe and French drains, closely adjacent to runways, are treacherous owing to invisible cavitation of sides. These drains must be closely examined after heavy rains for evidence of subsidence and caving. Open drains should be flagged for a distance of 10 feet from junctions with taxi-tracks or landing strips.

### SECTION 129.—PUNCTURES

A burst tyre during take-off or landing is one of the commonest and most dangerous contingencies, calling for engineer study and precautions. Sharp stones, outcropping rock, metal fragments, particularly after heavy A.A. fire, are the chief causes of trouble. Sommerfeld track, worn into a broken condition, has a bad reputation for damaging tyres and tail-wheels. Anything which might puncture or damage a motor car tyre is certain to damage and cause a burst in the case of an aircraft tyre, since the tread and walls of the latter are comparatively thin. A tyre burst taking off invariably causes a serious accident. Strips and tracks must, therefore, be cleared of anything which might damage a tyre.

### SECTION 130.—FLYING OBSTRUCTIONS

In spite of every effort to observe restrictions, actual or psychological obstructions in the flying approach are common causes of accident. Obstacles cannot always be removed, and, even when clearly marked by danger signals, their adverse influence will often be indirectly

responsible for bad take-offs or landings. When there are obstructions in the approach the advice of the Airfield Commander or Flying Control Officer should be obtained as to which should be removed or marked. If practicable, all obstructions which do not allow an angle of 1 in 50 should be removed.

### SECTION 131.—SLOPES AND UNDULATIONS

Dangerous undulations rarely escape attention, but a camber or transverse slope, too heavy for safety, is more often overlooked. This is liable to promote uncontrolled swinging and is particularly dangerous, in cross winds, upon a slippery surface, such as that presented by a muddy pierced steel plank runway. With heavy slope, a greater width of runway or prepared surface is needed to offset the effects of this tendency.

### SECTION 132.—WORKS IN PROGRESS

1. Although it would appear to be superfluous to point to the danger inherent in work upon or adjacent to an active runway, the number of accidents which do actually occur under this head make it difficult to over-emphasize the need for thorough precautions. Accidents may be due to debris or plant being left in dangerous positions, to work proceeding too close to strips in service or to men not being withdrawn soon or far enough. Men in charge of parties often fail to appreciate the difficulties of the pilot in observing the ground below or in front of him, apart from the factor of flying speed. It should be assumed that the pilot will fail to see men or equipment.

2. When withdrawing to one side of a runway, in cross-wind, the windward side, often selected, is the more dangerous, for light aircraft in trouble tend to "weather-cock" into wind.

3. Just as runways are made wider and longer to minimize risk of accident due to causes not always technically justified, so must warning crosses and flags be employed with some measure of extravagance. Risks must often be taken for operational reasons, but accidents are most common when alertness declines owing to seeming security. Bad visibility due to dust storms or rain or poor light is a contributory factor of importance.

### SECTION 133.—FOREST AIRFIELDS

A landing ground in heavy forest presents operational dangers due to eddies and blanketing effect. For example, the landing lanes cannot always conform to the exact wind direction; accordingly, the pilot approaching for landing in wind velocities of a slight breeze or above is correcting drift whilst flying or gliding-in at the required air speed. When nearing the level of the tree tops eddies will occur which will require correction, but as the aircraft reaches a level below the trees it enters into a calmer zone created by the blanketing effect of the trees. The higher the wind velocity, therefore, the greater the danger. Even when flying over woods and forests at low altitudes, both by day and night, the air is usually turbulent and forest landing grounds should be avoided if possible. However, if such a landing ground is necessary, then the strips should be wider to allow for swing. Along the edges of the cleared area, trees should be lopped off at an angle to reduce sudden changes of wind velocity.

## CHAPTER 20

MECHANICAL EQUIPMENT FOR AIRFIELD  
CONSTRUCTION

## SECTION 134.—GENERAL

1. A sound basic knowledge of mechanical equipment, acquired mainly by practical experience, is essential to all engineer officers responsible for reconnaissance of sites, and construction of airfields. Although operation and maintenance will be performed chiefly by specialists, airfield engineers need to be familiar with the scope and capacity of a wide range of plant, from quarrying tools to surface finishers.

2. In this chapter, brief descriptions will be given of all types of plant normally used by British and American engineers upon airfield construction, with the exception of quarrying equipment which is standard for all stone users.

3. The choice of airfield equipment is influenced by the following special considerations :—

- (a) Abnormal demand for maximum capacity of plant during a short period, and in a concentrated area. Maximum speed is always the first demand.
- (b) Work often undertaken in clouds of dust, leading to heavy maintenance demands.
- (c) Opportunities for using different specifications at the ends and middle of runways, and for taxi-tracks and standings.
- (d) Concentration of work which facilitates supervision and often allows manual labour successfully to replace plant when it is urgent to conserve mechanical equipment.
- (e) Airfield construction requires, more commonly than any other operational task, equipment suitable for transportation by air in aircraft or gliders.
- (f) Airfield tasks are predominantly problems of area rather than of volume, owing to the flatness of sites selected and to the undesirability of heavy fills, despite the efficiency of modern compaction technique. On this account the motor grader, commonly known as the "Autopatrol", is a very important tool of airfield engineers.
- (g) Many items of plant in common use on airfields were unknown in English road construction before the war.

4. The tables of productive capacity, assuming average soil and efficient plant control, are extracted chiefly from standard tables, given in War Office and Air Ministry publications and U.S. Aviation Engineers' TM5-255.

## SECTION 135.—TRACTORS AND TRACTOR EQUIPMENT

1. **Crawler tractors.**—Crawler tractors are robust diesel or petrol-driven machines so designed that there is minimum ingress of grit and mud into the working parts. The wide track area enables them to work and maintain the draw-bar pull on soft or bad ground. A rear power take-off is fitted for operating power control units and winch gear. Five makes of American machines of different characteristics are supplied to the British army, as shown in Table XIII below :—

Table XIV.—Characteristics of crawler tractors

<i>Tractor</i>	<i>Draw bar H.P.</i>	<i>Maximum Draw bar pull—tons</i>	<i>War Office and Dominion classification</i>	<i>Maximum scraper size cu. yds. struck</i>
Allis-Chalmers H.D.14	132	12½	Class I	12
Caterpillar D.8 ...	113	11½		
Allis-Chalmers H.D.10	86	8½	Class II	9
Caterpillar D.7 ...	80	9½		
International T.D.18	71	8½		
Allis-Chalmers H.D.7	60	5½	Class III	6
Caterpillar D.6 ...	55	6½		
International T.D.14	54	6		
International T.D.9	39	4	Class IV	4
Caterpillar D.4	36	3½		
Allis-Chalmers W.M	33	2½	Class V	
International T.D.6	29	3½		
Caterpillar D.2 ...	26	2½		
Clark Airborne ...	20	—	Class V	2
Cletrac H G. ...	18	1½	Class V	2

Tractors can be used either as hauling units or for a variety of earth-moving tasks with the aid of auxiliary equipment.

2. **Bulldozer.**—A hydraulic or cable-operated pusher-blade fitted squarely across the front of a tractor. Used for spreading and levelling loose excavated material, clearing walls, hedges, brushwood and other obstructions from sites, and filling in craters.

*Performance of bulldozers*

<i>Length of push in feet</i>	<i>Type of tractor—</i>			
	<i>Cl. I</i>	<i>Cl. II</i>	<i>Cl. III</i>	<i>Cl. IV</i>
	<i>Output in cu. yds. per hour on level site, favourable soil</i>			
20	300	210	160	120
50	160	125	81	54
100	100	85	50	36
150	75	58	35	26
200	55	43	27	19
300	40	31	18	14

3. **Angledozer.**—Similar to the bulldozer. The blade can be angled up to 30 degrees horizontally, and tilted so that one corner of the blade is approximately 6 inches lower than the other. The standard bull and angledozer equipment supplied to the British Army is normally hydraulically operated, but a percentage may be cable operated.

*Performance of angledozers.*—Favourable soil—level site

Type of tractor	Cu. yds. per hour
Cl. I	190
Cl. II	150
Cl. III	115
Cl. IV	85

Performance figures for different types of soil may be determined by the use of the following table :—

Table XV.—Coefficient table

Favourable soil (loam)	1	Blasted rock	} 0.3 —0.4
Average Earth : sand	0.8—0.9	Hard clay	
Soft clay, gravel	0.65—0.75	Rubbery clay	
Boulder clay	0.45—0.65	and chalk	

4. **Wheeled tractors.**—These are high-powered pneumatic tyred tractors, developing 30 draw-bar h.p. Used for hauling rollers, trammels, mowers, rotary brushes and other light plant.

## SECTION 136.—SCRAPERS

1. **Scrapers.**—These machines consist of a steel "box" with a cutting edge, mounted on four wheels. An apron lowered over the intake prevents the material spilling during transit. The load is dumped by raising the apron, allowing the spoil to be ejected by the forward movement of a tailgate. Tractor drawn, they are controlled by the operator through a power control unit fitted to the tractor. Some scrapers are hydraulically controlled in a similar manner to the angledozer. They are destined to excavate, load, transport, dump and spread the excavated material.

Scrapers are of 4, 6, 8, 12 cubic yards struck capacity. The 8 cubic yard machine is the most universal for airfield work.

Performance depends on the type of material loaded, and the length of haul.

Average results for favourable soil :—

Length of haul in feet.	Tractor	Scraper	Cu. yds. per hour
500	Cl. II	8	95
600	Cl. II	8	80
800	Cl. II	8	60

For maximum production the scraper should be loaded as it moves down grade.

**2. Tournapull-drawn scraper.**—The tournapull is a two-wheeled tractor and replaces the fore carriage on a scraper. The result is a motorized scraper driven through two large pneumatic-tyred driving wheels. Having less adhesion than a tractor-drawn scraper, it usually requires the assistance of a tractor whilst cutting. When loaded, the high road speed is ideal for long hauls. The tournapull can be economically used on hauls from 1,200 yards to 3,500 yards, as against the economic limit of 1,200 yards of the tractor-drawn scraper.

Average performance in favourable soil—12 cubic yards scraper—Class II tractor pushing :—

<i>Length of haul in feet</i>	<i>Cu. yds. per hour</i>
800	115
1,000	90
2,000	75

**3. Rotary scraper.**—Consists of a bowl 4–7 feet long, 2 feet 4 inches in diameter, attached to a towing bar. A trip lever controls loading and spreading operations. Only suitable for light work, involving short hauls.

*Performance.*—Cubic yards per hour in favourable soil.

<i>Length of haul in feet</i>	<i>Size of bowl</i>	
	$\frac{3}{4}$ cu. yd.	1 cu. yd.
50	26	40
150	12	18

## SECTION 137.—GRADERS

**1. Tractor-drawn blade graders.**—A heavy frame mounted on wheels, with a blade 8–12 feet long, which can be regulated either horizontally or vertically to suit different tasks. The machine may be traversed across the rear axle; set at an angle to the front axle, and the depth of cut regulated.

Used for grading the surface of airfields, cutting ditches and shaping banks. Scarifiers, fitted between the blade and front axle, increase the utility of the machine, which, although difficult to manœuvre, is suitable for some classes of heavy work on account of the great tractive effort of the tractor. For average service, in operational areas, this type of grader is unable to compete successfully with the motor grader which is easy to reverse and to move from task to task.

*Performance*

<i>Nature of Work</i>	<i>Capacity per hour</i>
Scarifying and shaping sub-grade     ...     ...	400 sq. yds.
Spreading material—base course     ...     ...	200 cu. yds.
Drainage—ditches     ...     ...     ...     ...	300 cu. yds.

2. **Motor grader.**—A self-propelled version of the blade grader, having the power unit situated to the rear of the blade. The power-operated blade is adjustable through a wide range of positions to facilitate operation. The front wheels can be set to lean at an angle in order to counteract the thrust due to oblique cutting and to reduce slippage on sloping ground. When working in difficult ground, the additional power of a tractor may be required, especially when the scarifier is being used. Can also be used in reverse. On the road, they are capable of a speed of 12—15 miles per hour. The average working speed is 3 m.p.h. Easily adapted for clearing snow, scarifying work and pulling trammels or rollers, these machines are invaluable for shaping and grading formation, loosening soil to a uniform depth, forming windrows, mixing, spreading and finishing of materials used in the construction of mix-in-place surfaces.

#### *Performance*

<i>Nature of work</i>	<i>Output per hour</i>
V Ditches, sandy soil ... ..	450 cu. yds.
V Ditches, common earth ... ..	300 cu. yds.
Scarify and shape sub-grade ... ..	400 sq. yds.
Spreading base course ... ..	200 cu. yds.
Shaping surface ... ..	450 sq. yds.
Pavement construction—mix-in-place—bituminous material ... ..	150 sq. yds.

Because of their mobility and wide service, there is a common temptation to give the motor grader tasks too heavy for its design. The machine's foremost role is that of a light or medium surface grader, on which work an area of 7,000 square yards per hour has often been accomplished in desert country.

3. **Improved graders.**—The Trammel Scraper consists of a long timber or metal frame, to the underside of which four or five steel channels are attached. These channels may be set at an angle to the frame. Trammels remove small ridges or mounds and fill depressions. Easy to dismember and transport.

Railway Rail and Channel Scrapers are usually 18 feet long. They are made double or single, and towed by lorry, motor grader, or wheeled tractor at an angle to the line of progress by adjustment of the tow-ropes.

### SECTION 138.—SCARIFIERS AND ROOTERS

1. **Scarifiers** are sets of teeth fitted to road rollers and motor graders. They are used for breaking up hard surfaces.

Under reasonable working conditions, 100—300 square yards per hour may be scarified.

2. **Rooters.**—Very heavily constructed scarifiers, with 3—5 strong tynes, drawn by a Class I or II tractor. The tynes, with a maximum penetration of 2 feet 3 inches, are controlled by wire rope, operated by the P.C.U. on the tractor. For exceptionally hard conditions, the centre tooth only is used. Rooters will easily break up hard sunbaked

clay and even soft rock. They are principally used to loosen the ground over which scrapers are working, thereby increasing the performance of the scraper. They are also extremely efficient for breaking up concrete.

Rooters have been used extensively to win disintegrated surface stone for crusher plants providing material for runway pavements.

Three standard models are manufactured by the Le Tourneau Company :—

K.30—Extra heavy duty—3 teeth each weighing  $4\frac{1}{2}$  cwts.—designed for use with Class I tractor.

H.3—Heavy duty, 3—5 teeth—Maximum penetration 29 inches—Class I tractor.

S.3—Light duty, 3—5 teeth—Maximum penetration 20 inches—Class II tractor.

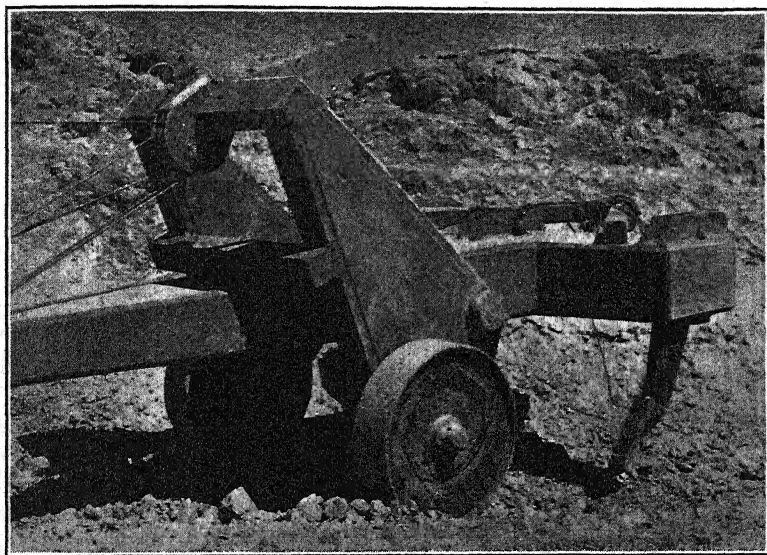


PLATE 50.—ROOTER—3-TYNE, CABLE OPERATED

#### SECTION 139.—EXCAVATING MACHINERY

1. An **excavator** is a self-propelled power-operated digging machine, which can be fitted with various items of equipment for airfield work.

- (a) *The drag line* used principally for excavating below its own level or below water level; the bucket being suspended by cable from the end of a long jib and filled by being dragged towards the machine.
- (b) *Power or face shovel*.—The digging bucket is attached to a rigid arm and capable of being forced upwards through the earth. Used chiefly against the bank or face of material.
- (c) *Skimmer*.—A modified power-shovel, having a horizontal boom used for shaping to contour by surface excavation.

- (d) *Backacter*.—The digging bucket is fitted to a shovel arm which is pivoted to a jib or boom. To fill, the bucket is drawn upwards towards the machine. Primarily used for digging drainage trenches, it is useful for clearing out mud and pulverized material from craters.
- (e) *The grab* consists of a bucket, with strong curved steel teeth or jaws, controlled by wire ropes for clutching or gripping material to be removed. Not normally supplied for use on airfields.

The machines used by the Army have a bucket capacity of  $\frac{3}{8}$ ,  $\frac{1}{2}$  or  $\frac{5}{8}$  cubic yard "struck" measure.

#### *Performance*

Approximate maximum output (solid measure) in cubic yards per hour in favourable soil.

<i>Capacity of bucket</i>	<i>Face shovel</i>	<i>Backacter Dragline Skimmer</i>	<i>Grab</i>
$\frac{3}{8}$ yd.	40	35	20
$\frac{1}{2}$ yd.	47	45	25
$\frac{5}{8}$ yd.	60	55	35

2. *Traxcavator*.—Is a specially equipped Class IV tractor, to function as a small excavator. An "H" frame, with a cable-operated sliding bucket of  $\frac{3}{8}$  cubic yard capacity, is mounted vertically in front of the tractor. The bucket is dozed into a heap of sand, soil or rubble, and raised to the top of the frame when full. The tractor can then discharge its load wherever required. It has been used successfully in operations, mainly for loading lorries, taking the place of much less mobile excavators.

3. *Elevating grader*.—A power or towed grader, with plough collector and elevating attachment, designed for skimming off a long furrow of material, loading on to transport, or depositing clear of the task. Used for digging drainage trenches, excavating fuel-storage dumps on airfields, and the exploitation of borrow pits, where the carry or haul is by Athey wagon, dumper or tipper.

It is an earth-moving, not a finishing machine, such as the towed grader or motor grader. Under good conditions, up to 400 cubic yards per hour can be dug and loaded into transport. Where spoil is cast on to the banks, the output may be increased to 700 cubic yards per hour.

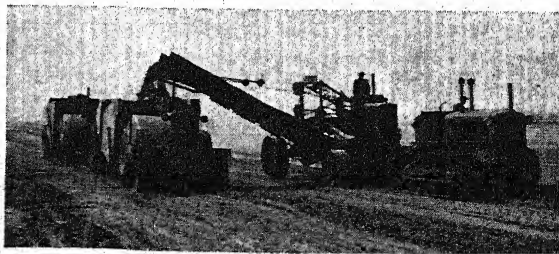


PLATE 51.—ELEVATING GRADER.

4. **Bucket trenchers.**—Heavily used in airfield construction on drainage work. Designed to produce a clean cut narrow trench to a maximum depth of 4—6 feet. Mounted on crawler tracks, they consist of a driving unit, control gear, excavating mechanism and conveyor. The excavated material is deposited at right angles to the axis of the machine.

The excavating mechanism is a continuous chain of buckets 12 to 18 inches wide, rotating around a boom or wheel, which can be lowered into the ground. This can be set either vertically for working or drawn clear of the ground for travelling. Can excavate at the rate of 50 to 150 yards an hour according to the type of ground. (See Plate 13.)

#### SECTION 140.—PLOUGHS

1. **Mole plough.**—A horizontal boring tool, 3 inches in diameter, carried at the end of a vertical knife, having a maximum cutting depth of 30 inches, mounted on a wheeled frame for towing by a Class IV tractor. Used for making agricultural tunnel drains in clay soils of suitable consistency. It may also be used for laying long cartridges of explosives in the ground for demolition purposes, or with suitable attachments for laying electric cables.

2. **Killifer plough.**—A large double-breasted plough, capable of making a V-shaped trench 26 inches deep, 12 inches across the bottom, 48 inches wide at the top. Tractor towed, it is supported on two large steel-rimmed wheels. The depth of cut is set by hand before operation. Used for cutting drains and cable trenches. In hard ground, the surface must be broken with a single-tyne rooter before ploughing.

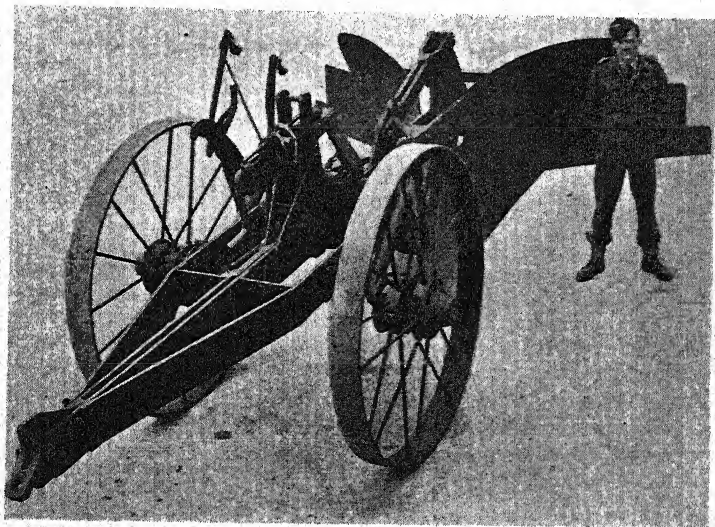


PLATE 52.—DITCHER—KILLIFER PLOUGH

## SECTION 141.—HARROWS

1. **Disc harrows.**—One type consists of four sets of eight discs fixed in steel frames, and coupled together in two lines each of two sets. The discs are in line with the direction of progress. The other type is made up of four 4-disc units, which are attached in pairs to two identical T-shaped frames connected in tandem. The stems of the frames point forwards, the front one being attached to the tractor, and the rear one to the centre of the cross piece of the front frame. The disc units are bolted one to each end of the cross pieces and attached by the rods to the stems, so that they are set at an angle to the line of progress. The set of the front discs is forward, and that of the rear discs backwards. Used for breaking down lumpy soil before grading and trammelling, and in the preparation of stabilized surfaces.

2. **Cultivator.**—A tractor-drawn metal frame, 8 feet wide, supported on two wheels to which are attached 16 adjustable tynes, 12 inches apart. Used to loosen, break up and mix soil after scarification and for progressive stages in stabilization.

## SECTION 142.—ROLLERS

1. **Power-driven rollers** supplied for airfield work are either three-wheel all-purpose rollers or tandem type. Models range from 2–16 tons. The small sizes are petrol-driven, the larger by heavy (Diesel) oil engines. 5 and 8-ton rollers used by the American Aviation Engineers are two-axle tandem type. Heavy duty rollers are normally fitted with a scarifier.

*Performance of 5–8-ton power-driven rollers*

<i>Nature of work</i>	<i>Surface covered per hour</i>	<i>Condition</i>
Sub-grade preparation	1,000 sq. yds.	3 m.p.h. 5 passes.
Base course compacting gravel	300 sq. yds.	
Base course compacting macadam	75 cu. yds.	
Surface dressing	3,000 sq. yds.	Rolling aggregate. 3 m.p.h. 3 passes.
Surfacing	1,500 sq. yds.	3 m.p.h. 6 passes.

2. **Sheepsfoot rollers.**—Are heavy, hollow cylindrical drums, 3 to 4 feet in diameter, with projecting feet 7 to 9 inches long, arranged in rows round the drums. Drums may be coupled together or used as single sections. Towed by tractor, either singly or in multiples, in line or offset in the direction of the tractor. For extra heavy work, the drum of the roller can be filled with sand or water. (See Plate 17.) Some models are fitted with detachable feet.

Used for compacting a considerable range of loamy soils, they are not effective on sand, gravel or crushed rock, without a binder, and can not be used effectively on heavy clay, especially when wet. Best results are obtained when the material to be consolidated is spread in 5 to 6-inch layers.

*Performance of sheepfoot rollers—two drum in line towed by 30 d.b.h.p. tractor*

<i>Nature of work</i>	<i>Performance per hour</i>	<i>Remarks</i>
Sub-grade preparation ...	650 sq. yds. 540 sq. yds. 450 sq. yds.	6-in. layers 8 passes. 6-in. layers 10 passes. 6-in. layers 12 passes.

**3. Pneumatic tyred roller** (wobbly wheeled roller).—This is one of the most valuable items of plant used in airfield construction. The best type comprises a chassis with 8-13 pneumatic tyred wheels operating independently, in a wobbly fashion, off two eccentric axles. The front wheels are aligned to cover the spacing between the rear wheels. Additional weight is obtained by loading the chassis with sandbags. Used after a sheepfoot roller, they knead the surface into a smooth base, and are employed for compacting stabilized mixtures and bituminous surfaces. Towed by a 30 d.b.h.p. tractor, 5 passes at 5 m.p.h., they will, roll an area of about 3,000 square yards in one hour. (See Plate 53.)



PLATE 53.—RUBBER TYRED ROLLER—TOWED,  
13 ROLLER WHEELS. WESTERN DESERT

Satisfactory rubber tyred rollers can be improvized from sets of old aircraft wheels. (See Plate 22.)

**4. Corrugated concrete roller.**—A corrugated steel drum, filled with concrete, well rammed into the corrugations in 6-inch layers. A 600-gallon water distributing tank can be superimposed above the roller. Towed by a Class IV tractor or by other means, they can be used, in lieu of sheepfoot rollers, for soil compaction.

5. **Tracked roller.**—A normal tractor, with smooth closely-fitting track plates, which has been widely used in England for the initial compaction of bitumen sand-mix surfaces.

6. **Snow rollers.**—These are usually large light rollers of approximately 8 feet diameter, 10 feet long, and weigh approximately 1,000 lb. They can be towed at normal speeds by a light tractor and can consolidate 6 inches of snow to 2 inches in one pass.

7. **Improved rollers.**—Rollers are frequently constructed from local materials, using steel cylinders of various sizes filled with concrete and attached to suitable towing devices.

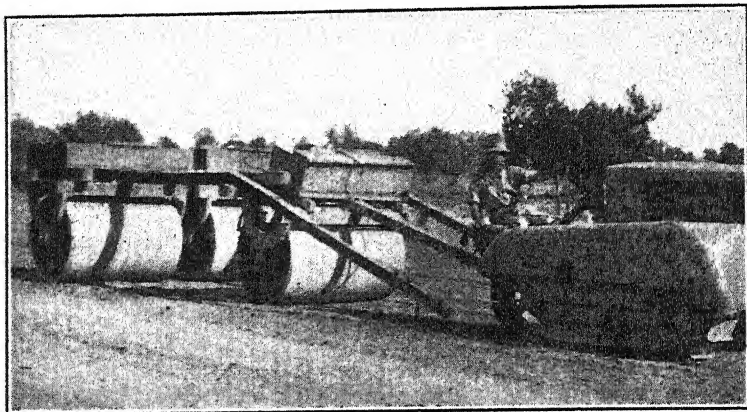


PLATE 54.—TRIPLE ROLLERS—TOWED, SMOOTH—  
ON CYPRUS RUNWAY

#### SECTION 143.—ROTARY SWEEPER AND MOBILE MAGNET

1. **Rotary sweeper.**—A fibre or wire broom towed by a wheeled tractor, or fitted to a motor-grader. Used for removing sand, dust, gravel and light snow from runways and taxi-tracks; also for cleaning surfaces, and in preparation for bituminous applications. Valuable for sweeping bomb and shell fragments or "crow's feet" from paved runway surfaces.

2. **Mobile magnet for clearance of metal fragments.**—A mobile magnet, attached to the front of a Class IV tractor has been developed experimentally for the purpose of clearing, from airfield runways, bomb and shell fragments, crows feet and other pieces of magnetic metal liable to penetrate the tyres of aircraft and servicing vehicles.

It consists of 12 electro-magnets suspended from two 16-ft. carrying-channels, carried on two beams fastened to the side arms of the angledozer yoke. Wheels with axle bearings of variable height, are mounted at each end of the magnet carrying-channel to maintain ground clearance at the desired height. Loops of chain, on a 16-ft. T-piece, drag on the ground in front of the magnets, thereby loosening any embedded material.

A 4-kw generator fitted on a frame at the rear of the tractor provides the power for the magnets.

## SECTION 144.—BITUMEN PLANT

1. **Mixers.**—These machines are designed to provide a flow of uniformly mixed aggregates and bitumen. Some types can be used as travelling mixers, picking up aggregate from windrows, mixing and laying it. Stationary types are used at central mixing stations or moved from point to point as the work progresses.

- (a) *Barber-Greene mixer.*—The mixer hopper (1 cubic yard capacity) is fed by means of a reciprocating feeder and elevator. The aggregate is then conveyed along an apron feeder to the pugmill. Before entering the pugmill, a coat of bitumen is sprayed over the aggregate from a spray bar regulated by a metering pump, which is fed from a 350-gallon insulated tank on the mixer frame.

Mixing is by twin paddle-shafts, revolving in opposite directions; each shaft having eight paddle arms, the tips of which force the mix towards the discharge end of the pugmill. The mix is deposited on the surface, or into trucks by means of a "hot material" conveyor, driven by an extension shaft from one of the paddle shafts. Will produce 15–30 tons of material an hour, according to the type of aggregate (see Plate 55).

- (b) *Wood road mixer.*—This smaller type has been used in North Africa with moderate success, for airfield construction. It has a rotary paddle shaft, with 12 double-ended paddle arms, adjusted to regulate the flow of the mix. The mixer drum rests on the ground; a spiral blade, in advance of the paddle arms, assists the introduction of the windrowed material into the mixer drum, where it is sprayed with bitumen, which is delivered under pressure from a towed tanker. A Ford V.8 engine, mounted at the rear of the mixer, delivers the bitumen from the tanker, and also provides air for the pressure burners fitted to the mixer drum.

- (c) Other travelling mixers used on airfields are the Iroquois, Jaeger, and Stothert and Pitt Mixers.

A pre-heating bitumen plant and two insulated bitumen trailers are required to maintain the supply of bitumen for travelling mixers.

- (d) *Millar Mixer* (10 cubic feet capacity).—These machines are mounted on four steel-rimmed wheels and fitted with a tow bar. The mixing drum, with twin shaft paddles, is fed by a power-elevated skip (10 cubic feet capacity). Bitumen or tar is pumped from an independent tar-boiler, into a trough baler, where the correct quantity for each batch is measured. The bitumen or tar supply is in constant circulation. The trough baler is fed from a hand-operated tap, emptied into the mixer drum and refilled for the next batch. The mix is discharged through a hand-operated discharge door. A 14 h.p. diesel or petrol engine operates the mixer drum, bitumen pump and the elevating mechanism of the skip. All controls on the machine are operated by one man. Under normal working conditions, will produce 10 tons of mixed material per hour. (See Plate 45.)

May be used, together with a drying machine. For direct discharge into lorries, these machines are sometimes raised upon suitable structures or are served by a sunken lorry road.

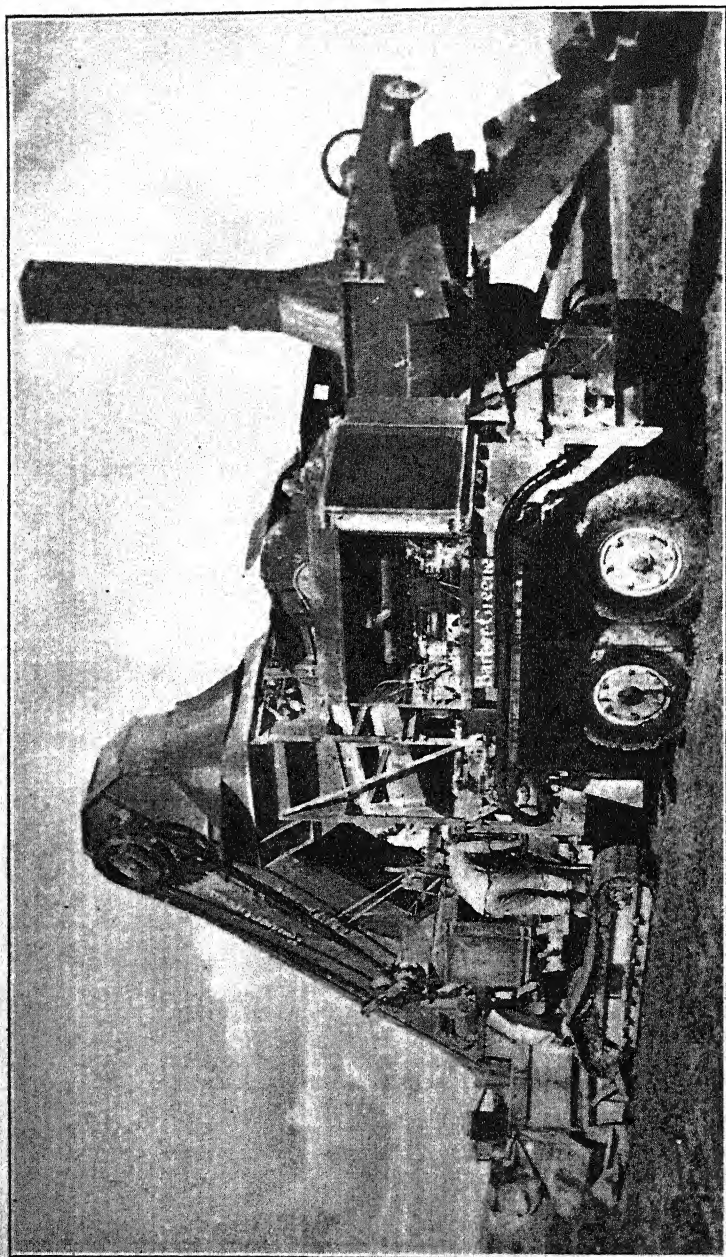


PLATE 55.—BARBER-GREENE MIXER USED AS STATIONARY PLANT. TUNISIA

**2. Asphalt finisher or paver.**—This crawler-tracked, self-propelled unit is used for laying mixed bituminous materials on airfield pavements. It is a tamping and automatic levelling machine capable of laying material  $\frac{1}{4}$  to 6 inches thick, 8 to 12 feet in width, at speeds from 7 to 44 feet per minute. The average laying capacity is 100 tons per hour depending on the type of mix or thickness of pavement. The mix is usually supplied to the paver from dump trucks. It can be used for laying and finishing material produced by a travelling mixer.

**3. Tar boiler.**—This consists of a chassis mounted on four steel-tired wheels, containing a 250-gallon cast iron boiling pan. A fire-box, burning coal or fuel-oil, heats the tar or bitumen. Fitted with one or two spray distributors, and a davit for hoisting the tar barrels above the boiler. Towed by a roller or tractor, or horse-drawn.

**4. Bitumen tank.**—This consists of a trailer-mounted tank of 1,000-to 1,500-gallon capacity. A 28 h.p. boiler generates steam for heating the bitumen. It is used for maintaining a continuous supply of bitumen for travelling mixers, and asphalt distributors.

**5. Bitumen distributors.**—1,200-gallon or 1,500-gallon trailer-mounted tanks used for heating, transporting and distributing or spraying bituminous material over large areas.

1,250 square yards per hour can be covered at the rate of 0.2 gallon per square yard using a 24-foot spray.

#### SECTION 145.—CONCRETE MIXING, SPREADING, AND FINISHING MACHINERY

**1. Concrete mixers.**—For airfield purposes, mixers provided are of the small portable type, varying in capacity from  $3\frac{1}{2}$  to 14 cubic feet. Mixer sizes are denominated by two numbers, the first representing the approximate volume in cubic feet of unmixed material which the mixer will take, the second number the approximate output in cubic feet of mixed material. A 10/7 mixer will produce 7 cubic feet of mixed material from 10 cubic feet of unmixed material. Mixers are mounted on four wheels with a towing bar, for transport on the site. The mixing drum is driven by a small petrol engine.

*Approximate output for standard mixers*

<i>Mixer size</i>	<i>Number of batches per hour</i>	<i>Output per hour in cu. yds.</i>
7/5	20	$3\frac{1}{2}$
10/7	20	5
14/10	17	$6\frac{1}{2}$

For large scale concrete construction in static areas heavier equipment such as central mixing plant, paving, spreading and finishing machines may be available.

**2. Concrete paver.**—The concrete paver is used for the construction of large concrete pavements. It is a crawler-tracked, self-propelled concrete mixing unit, with a large charging skip into which the materials are discharged by dump trucks. The skip is raised to discharge its contents into a horizontally rotating mixing drum capable of producing 34 cubic feet of mixed concrete every 50—100 seconds depending on the setting adopted for the automatic mixing cycle.

The Koehring 34 E concrete paver has a double compartment mixing drum thereby enabling it to produce 34 cubic feet of mixed concrete every 60 seconds. The average output is 100 tons per hour.

The Rex Multifoot 34 E concrete paver has a single mixing drum, operating like the Koehring paver on an automatic cycle, whereby all necessary operations are automatically measured during each mixing cycle. In both types the mixed concrete is discharged from the drum into a bucket suspended from a projecting boom 35 feet long. Concrete can be dumped by means of this boom and travelling bucket over an area 32 feet in diameter.

Designed for use as a travelling mixer, the concrete paver is often used as a static mixer.

**3. Concrete spreader.**—This machine is designed to operate directly behind the paving mixer, and to spread the batch outputs of the paver into a continuous uniform slab of concrete between road forms set at a maximum width of 20 feet, which serve as rails on which the spreader travels.

A self-propelled unit mounted on four wheels, it consists of a spreader blade which can be set to work at any desired depth below the top of the road forms, spreading the paver batches across the road while the machine is advancing along the road forms. Behind the moving spreader blade is the strike-off plate, which can be arranged so that it leaves either a flat or a roughly cambered surface.

**4. Concrete finisher.**—Designed to operate directly behind the concrete spreader, tamping the concrete and imparting to it the final finish to the required surface level. It consists of a front sliding screed 20 feet long, 9 inches wide, followed by the vibrator pans and then the final finishing screed, 12 inches wide. All are adjustable to suit varying conditions of concrete mix, paving widths and finished surface levels.

**5. Colcrete mixer.**—The twin-tank machine is operated by either petrol, diesel or electric motor unit. In one tank, cement and water are combined to form a colloidal cement-water grout; in the other, sand is added to form a stable cement-sand grout. Grout is delivered to the site, through 2½-inch diameter rubber hose up to a distance of 150 feet. Output, about 18 cubic yards per hour.

#### SECTION 146.—P.B.S. LAYING MACHINE ("STAMP LICKER")

1. The function of this machine is to apply a liquid adhesive solvent to the underside of the Prefabricated Bituminous Surfacing and lay the material evenly on the ground.

2. This machine consists of a two-wheeled pneumatic tyred trailer, carrying a lower closed tank holding 120 gallons of petrol-oil solvent, and an upper tank of 30-gallon capacity, in which rotates a 16-inch diameter canvas-covered wooden roller, partly immersed in the fluid.

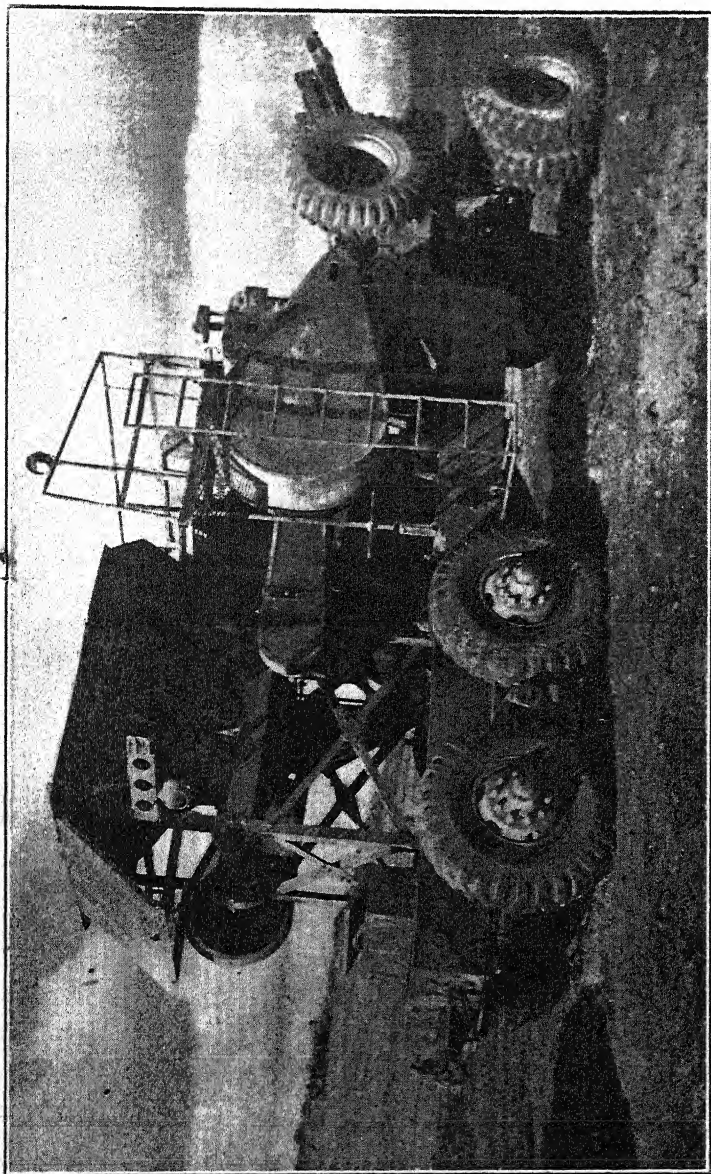


PLATE 56.—CRUSHING PLANT—SEMI-TRAILER MOUNTED, PETROL DRIVEN, CAPACITY  
25 TON/HR. TUNISIA

### SECTION 149.—AIRBORNE ENGINEER EQUIPMENT FOR ADVANCED LANDING GROUNDS

1. Airborne engineer equipment, sent forward into areas not accessible to overland movement, is selected for its compactness or suitability for ready dismantling and reassembly.

2. American experience in the Southern Pacific has led to the selection of the following plant, for a standard task, transportable by C-47 Transport Aircraft (door width 84 inches), or CG-4A Glider (door width 70 inches).

- (a) Crawler tractor, with bulldozer and winch, hydraulic controls, 20 h.p. tractor. Weight 4,230 lb., length 110 inches, width 49 inches.
- (b) Rubber-tyred tractor. Weight 3,300 lb., 123 inches by 56 inches.
- (c) Tractor-mounted  $\frac{1}{2}$  cubic yard shovel loader. Weight 4,200 lb., 144 inches by 56 inches.
- (d) Scraper  $1\frac{1}{2}$  cubic yard, towed, hydraulic controls. Weight 2,400 lb., 147 inches by 65 inches.
- (e) Trailer, dump, 2 wheel,  $\frac{1}{2}$ -ton. Weight 635 lb., 92 inches by 55 inches.
- (f) Grader, road, towed, 6 $\frac{1}{2}$ -foot mouldboard. Weight 1,875 lb., 174 inches by 70 inches.
- (g) Sheepsfoot roller, single drum with detachable teeth. Weight 3,060 lb., 132 inches by 60 inches.
- (h) Smooth roller, towed-type, 5-ton water-load. Weight 2,000 lb., 165 inches by 60 inches.

3. The limited capacity of airborne equipment and the consequent need for the avoidance of all unnecessary heavy tasks, puts abnormal responsibility upon the skill and judgment of the planning staff and the reconnaissance engineer. Favourable sites are essential.

### SECTION 150.—WATERPROOFING EQUIPMENT FOR DEEP-WATER FORDING

1. The best methods of waterproofing the major items of mechanical equipment used by airfield engineers, have been determined by extensive trials. Tractors, motor graders, motor scrapers, excavators, dumpers, rollers, and even portable crushing plant can be operated through 4 feet 6 inches of water for a period of six minutes, or for several hours, if waterproofed for continuous operation. To ensure complete success, equipment must be in perfect mechanical condition, and if used for continual wading, should be driven ashore after the first half hour, so that certain parts may be checked for excessive leakage.

2. Various sizes of copper tube are required to raise breathers above water level, also steel tubes for extensions to inlet and exhaust pipes and air filters. Steel tube connections are protected against vibration by the insertion of rubber tubes. Other precautions involve the use of:—

- (a) "*Denso*" putty.—A hard waterproofing putty for gaskets, coverplates, etc., at ordinary temperatures.
- (b) "*Denso*" plast.—A fairly high melting point compound used for protecting electrical equipment, sealing cracks, and the seams of covers. It is tenacious but easily worked. It must be applied thickly, with all edges "feathered" off and with the top smoothed over to present an unbroken surface.

- (c) "*Denso*" tape.—A waterproof adhesive tape which may be applied to metal surfaces or used as a bandage to cover recesses filled with Denso plast. It should be applied with  $\frac{1}{2}$  inch overlap, wound on like a puttee and the edges smoothed over with the hands.
- (d) "*Denso*" paste.—A jelly type material which may be applied to metal surfaces, and afterwards covered with Denso tape.
- (e) "*Bostik 692*"—A sealing cement.—In cold weather, warm slightly to give an easy flow of compound. Bostik 692 is used for joining waterproof fabrics or for attaching waterproof fabric to metal. It is painted on both the surfaces to be stuck together, and must be allowed to get nearly dry before the joint is made.
- (f) *Asbestos compound*.—May be used in place of Denso plast, if this is not available.
- (g) *Empire cloth*.—This is a waterproof fabric used for making bootees to fit on gearbox and clutch levers, etc.

3. All surfaces to which waterproofing compound is applied must be clean and free from all dirt, oil and grease, if a good seal is to be obtained.

The fuel injection pump breather should be opened within 12 hours after the tractor has left the beach. Engine and steering clutches and final drives to be checked for leakage. All waterproofing compounds should be removed within five days of landing and all parts thoroughly cleaned. Oil should be changed and all parts lubricated. It is essential that equipment be washed with fresh water to safeguard against the deleterious action of salt water.

4. The Engineer Board, Fort Belvoir, U.S.A., has issued instructions on the waterproofing of plant, allowing the submergence of both diesel and petrol engines. No special degree of skill is required. The operator, with the help of one man, can perform the task in 4 or 5 hours.

Pipes and fittings are used to raise breathers, vents, air cleaners and exhaust pipes above water level. The maximum depth of water practicable for tractors and graders is limited only by the length of these extensions and the depth at which operators can maintain control. Materials used include :—

- (a) Permatex gasket compound, for sealing all inspection plates and other covers liable to let water into different housings.
- (b) Friction tape to seal seams around air cleaners and to wrap sparking plugs, magnetos, generators and wire connections.
- (c) Insulating enamel to protect and seal pores in the friction tape.
- (d) Asbestos grease is applied over sparking plugs and wire connections immediately before entering water as an additional precaution against short-circuiting, and to cover the carburettor assembly.

On completion of landing, the tape round the magneto and generator must be removed, but otherwise no stripping or cleaning is necessary until a suitable opportunity arises.

## CHAPTER 21

## STANDARD TYPES OF TECHNICAL STRUCTURES

## SECTION 151.—GENERAL

1. The Army is responsible for the provision and erection of all structures required by the Air Force in operational theatres, with the exception of hangars, which are erected by the Army but are an Air Ministry supply.

Standardization of technical accommodation is adopted as consistently as war conditions will allow.

2. Standards for airfield layout and surfacing have to be observed, within narrow limits, for a single operation as for lengthy service. On the other hand, projects for technical accommodation will always be judged critically as to the urgency of the service rendered and to the term for which the service will probably endure. Big hangars for air-frame repairs or small dust-proof, well-illuminated buildings for instrument work may be needed for high efficiency, but so long as canvas-clad "nose" hangars or repaired buildings appear to be "good enough," urgency of completion leads to make-shift methods at a level falling short of standard types.

3. Engineer officers, responsible for advising Air Force Commands, and subsequent construction or adaptation, will need a good basic knowledge of the technical and administrative functions, for which provision has to be made.

4. Buildings and other structures will be classified under the following heads, ranging from simple operational needs to heavy commitments at the base :—

- (a) Advanced operational units.
- (b) Defensive operational units.
- (c) Signal buildings.
- (d) Control towers and offices.
- (e) Bomber units.
- (f) Maintenance units.
- (g) Hangars.
- (h) Pens.
- (i) Operational training units.
- (j) Parachute storage and packing.

5. For operations in Western Europe, bomber bases and maintenance services are retained in England as long as economically practicable. In these circumstances, in contrast with the conditions obtaining in a balanced force entirely overseas, services are performed by various authorities, including the Air Ministry, Ministry of Aircraft Production, Ministry of Works and the Admiralty.

6. The following sections are based upon the experience of R.A.F. Commands, in a distant theatre, of varying climatic conditions, where all branches of activity, from erection of new aircraft to salvage work in battle areas, were represented under a single command.

## SECTION 152.—ADVANCED OPERATIONAL UNITS

1. In operations, little call upon the engineers is made by these units, even when the situation becomes static for considerable periods of time.

2. Trailers and lorries are converted to suit different purposes. Fighter Group or Wing operational control requirements can be met by the assembly of these vehicles into an open square, with a canvas covering supported by a collapsible truss.

3. Advanced repair and salvage units, and associated air stores parks are essentially mobile, undertaking minor repairs in order to return lightly damaged aircraft to their units. Alternatively, aircraft are sent back to maintenance units in the rear, by air or by road transport, if too badly damaged for forward repair. The first demand of repair and salvage units is for easily-erected portable frame huts, canvas-covered, for workshops and stores.

4. Air stores parks are wholly mobile, being provided with store trailers and holding most of their stores in weatherproof packing cases.

5. If static conditions arise, a fighter wing and two or three squadrons operating from one airfield, may require temporary buildings or cut-and-cover accommodation.

One squadron would call ultimately for some or all of the following accommodation (scales shown for guidance only) :—

	<i>sq. ft.</i>		<i>sq. ft.</i>		<i>sq. ft.</i>
Operations room	120	Telephone exchange...	100	Wireless and battery room	240
Intelligence	150	Signals and ciphers	200	Crash ward and M.I. room	200
Armoury	300	Instrument repairs	240	Pilots' rest room	400

Armoury and instrument repair rooms must be reasonably dust-proof.

## SECTION 153.—DEFENSIVE OPERATIONAL UNITS

1. The role of these units is the protection of coastal convoys and the defence of ports, towns, installations, etc. Technical accommodation required is of a specialized character, chiefly for a chain of operational buildings with their ancillary "A.M.E.S." (Air Ministry Experimental Stations).

2. On the airfield, squadron requirements may, for example, include the following :—

	<i>sq. ft.</i>		<i>sq. ft.</i>		<i>sq. ft.</i>
Pilots' rest room	400	Crash ward and M.I. room	200	Signals	100
Wireless and battery	240	Instrument hut	240	Ciphers	100
				Armoury	300

Some defensive fighter airfields are provided with night fighter R.D.F. workshops (1,000 square feet).

3. The layout and design of operational buildings for coastal defence are always planned on a high staff level, but engineer co-operation may be urgently needed, especially when, as in built-up areas, existing buildings call for speedy adaptation.

4. A normal chain of command for operations is from command to group and from group to sector. The number of sectors to a group is variable.

As a rule, information from "A.M.E.S." is passed direct to group filter rooms, which in turn pass on relevant information to sector "ops." rooms for action. In certain cases, filtering by group is omitted and it is then carried out by sectors, commonly in a separate filter room.

Buildings required may include the following, apart from structures built for higher commands :—

Sector operations, with attached filter room (S.O.R.+F.R.).

Sector operations, with combined filter room (S.O.R.F.R.).

Sector operations (S.O.R.).

All the above will have their own attached signals receiving and W/T stations, varying in capacity from 4 to 24 channels.

5. Details of a typical overseas operations building, and of the controlling dais are given in Plates 58 to 60, showing efficient internal dispositions. Specially constructed buildings, well-lit and ventilated, are essential for the highest efficiency, but poorer standards may be accepted temporarily.

Group and sector requirements are practically the same, except that the group, not normally controlling aircraft in the air, does not need a triangulation room, but may require a bigger filter room for its greater area of responsibility.

6. The painting of maps on operations tables is done by R.A.F. personnel, but tables are an engineer supply. A common scale for maps is two miles to an inch. Tables are 10 feet in diameter, 2 feet high at the front and 3 feet at the back. Table tops must have a perfectly smooth surface to take a high class paint finish. Linoleum or a hard boarding such as "masonite" is most suitable, the latter allowing a better butt joint. Filter tables are rectangular, always level, and 2 feet 10 inches high. These need to be strongly built to carry the "plotters" who sit or lie on the table.

Triangulation tables are 4 feet in diameter and 2 feet 9 inches high.

#### SECTION 154.—AIR MINISTRY EXPERIMENTAL STATIONS

1. The majority of these units overseas are completely mobile and require little field work to be done, beyond blast protection for two to four technical vehicles.

2. One type of static station, shown in Plate 61, comprises receiver room, transmitter room, W.T. or controller's room and store.

3. It is important that receiver rooms, used much under blackout conditions, should be adequately ventilated. The transmitter room is noisy. Reasonable sound insulation should be provided. Instrument rooms must be as dust-free as possible.

4. A typical aerial-frame gantry has two separate stages, the lower, 10½ feet above ground, carrying a load of 6½ tons, with R.S.Js. resting on side the walls; the upper stage 20 feet above ground, serves to take the lateral wind-thrust on the aerial frame and to provide a platform for maintenance. Two generators, 20-k.v.a., are accommodated in separate power houses.

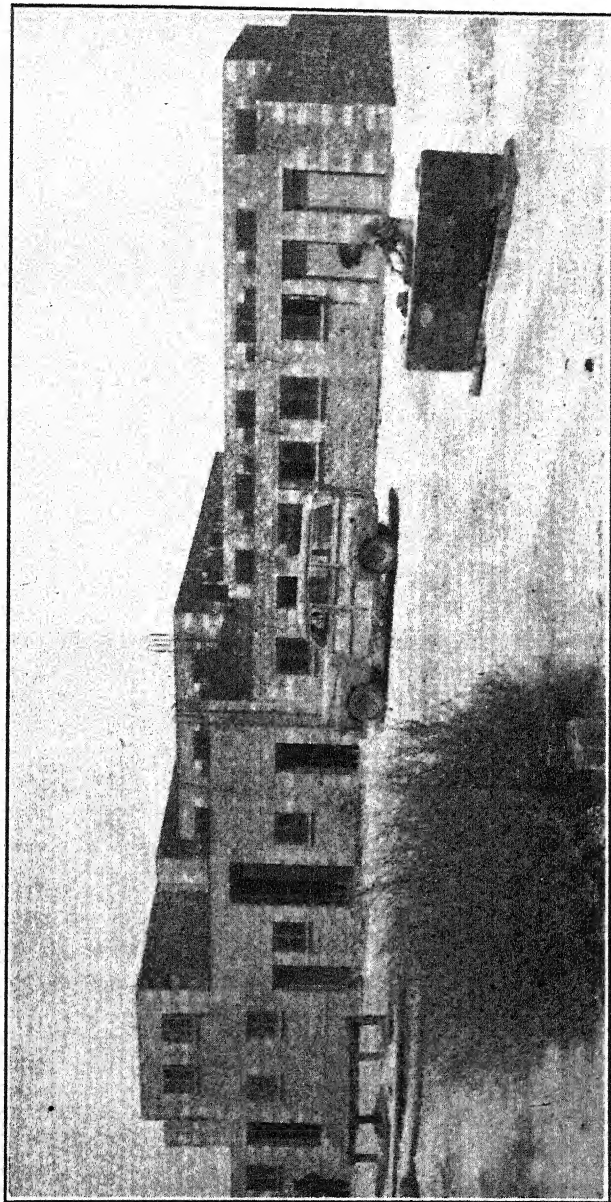


PLATE 58.—SECTOR OPERATIONS CONTROL BLOCK (S.O.R.)

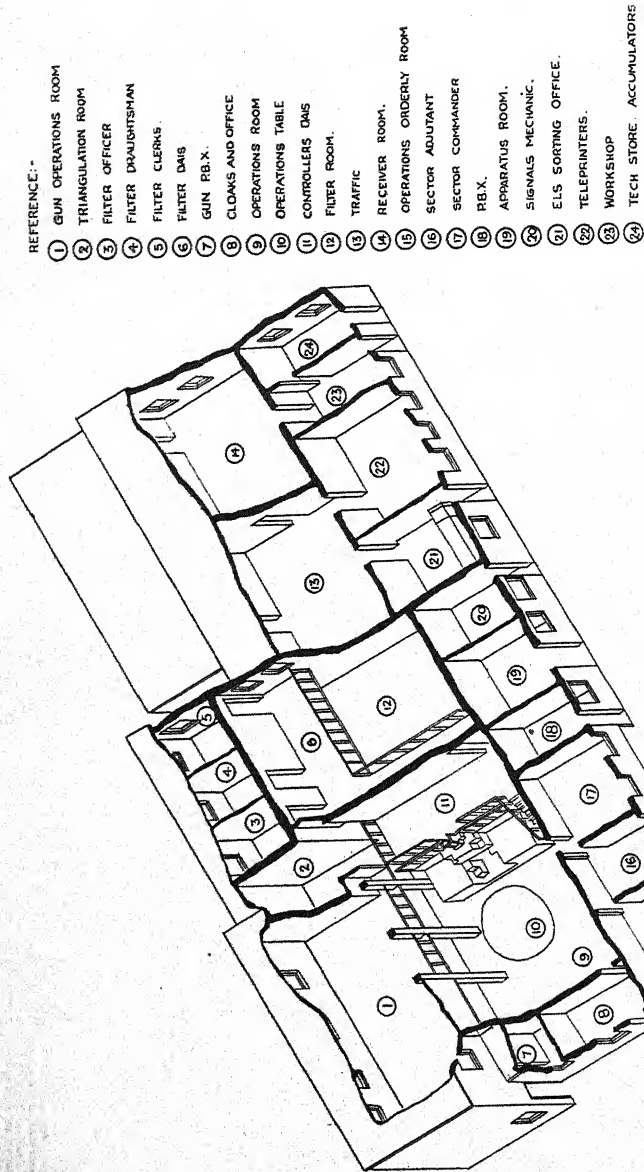


PLATE 59.—SECTOR OPERATIONS ROOM—PLAN OF SPECIALLY CONSTRUCTED BUILDING.  
(IN OPERATIONS ONLY ESSENTIAL ROOMS ARE PROVIDED, OFTEN IN ADAPTED BUILDINGS)

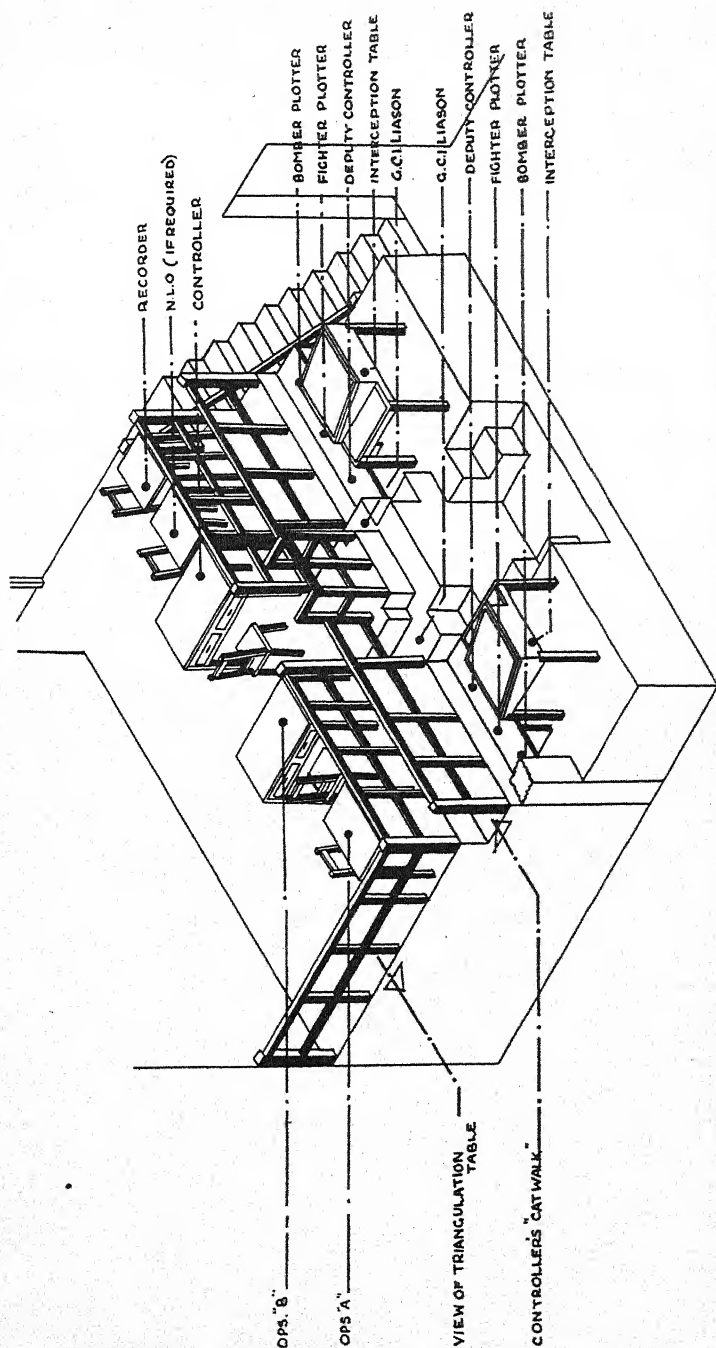


PLATE 60.—SECTOR OPERATIONS ROOM—TYPICAL DESIGN OF CONTROLLER'S DAIS

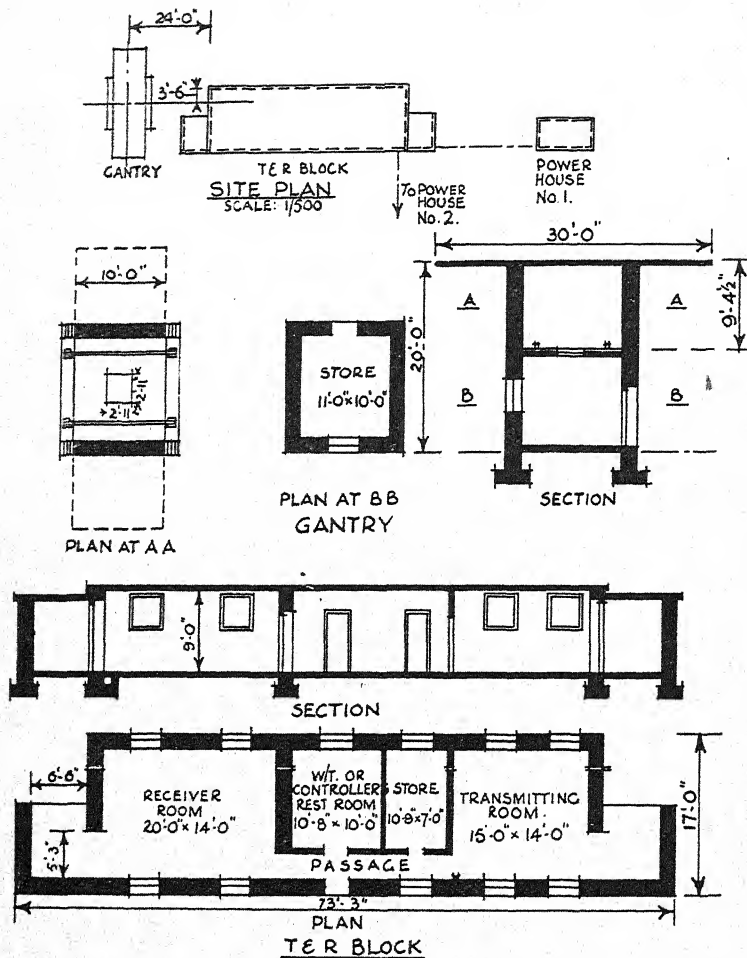


PLATE 61.--AIR MINISTRY EXPERIMENTAL STATION--  
TYPICAL LAYOUT

## SECTION 155.—SIGNAL BUILDINGS

1. Wireless communications are operated by R.A.F. Signals and land-lines by Air Formation Signals, a branch of R.C.S.

2. In mobile operations, R.A.F. signals equipment is housed in special vehicles. As soon as the situation becomes sufficiently static, and the siting of permanent centres can be attempted with reasonable confidence, new stations are built. These stations are easy to construct. Spans are small. C.G.I. and steel members should be avoided, particularly in transmitting stations.

Dust exclusion and temperature control are desirable. Type X (cipher) rooms should be sound-insulated, owing to the noisiness of the machines used. Accommodation required is dependent upon the number of channels and the functions of each particular station.

3. Standards for four or five channels may be roughly indicated as follows :—

(a) *W.T. station* :—

	<i>sq. ft.</i>		<i>sq. ft.</i>
Transmitter hall ...	300	Battery room ...	100
Office ...	120	Store ...	120
Workshop ...	120	Auxiliary power house	200

(b) *Receiving station*, providing for local traffic, would include :—

Receiver room, 200 square feet; teleprinters, 150 square feet; traffic, 150 square feet; also seven rooms for signals officer, ciphers, type X room, telephone exchange, stores, clerks and D.Rs., each 100-150 square feet.

4. **Air formations signals.**—With the exception of occasional main communication exchanges, accommodation called for by these units forms part of operational or administrative buildings.

Accommodation may be required for up to 30 teleprinters, a telephone exchange and some stores huts.

## SECTION 156.—CONTROL TOWERS AND OFFICES

1. A control point is necessary upon every airfield from which aircraft, either in the air or on the ground, can be directed, and to which all pilots must report on landing or before taking off. These are called "control office" or "control tower" for single or double-storey buildings respectively. Their functions are directed by the "flying control" branch, R.A.F.

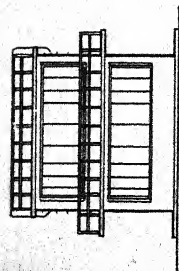
On small or advanced landing grounds control is often exercised from a hut or large tent, but on main permanent stations a large structure has to be built. *See Plate 62.*

2. In siting the tower or office, the "flying control" officer will seek :—

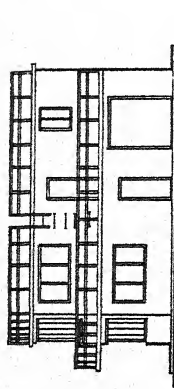
(a) Uninterrupted view of the whole airfield, including all dispersal areas if possible, with a good outlook on sides as well as to the front.

(b) A building which faces N., N.E., or E. (in order of preference) in order to avoid sun-glare. When this is impracticable, the building should be aligned on any other cardinal point of the compass, to help the control officer to find direction quickly when locating aircraft flying in.

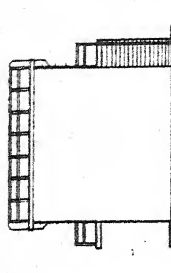
Buildings include control room, office, rest room, movements office and night flying equipment room.



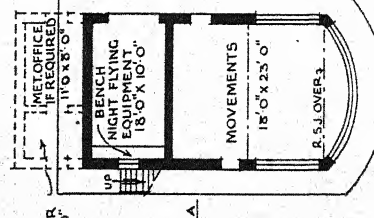
FRONT ELEVATION



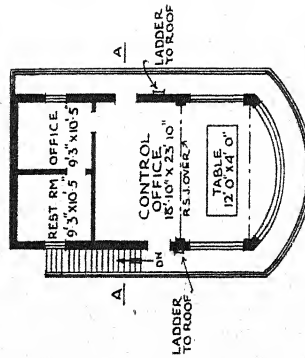
SIDE ELEVATION



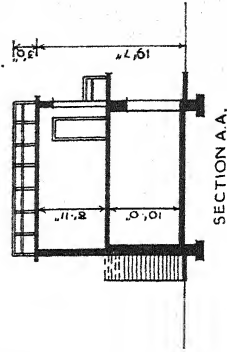
REAR ELEVATION

HYDROGEN  
GENERATOR  
6'0" X 6'0"

GROUND FLOOR PLAN



FIRST FLOOR PLAN



SECTION A.A.

PLATE 62.—CONTROL TOWER—TYPICAL ACCOMMODATION OF SMALL INSTALLATION

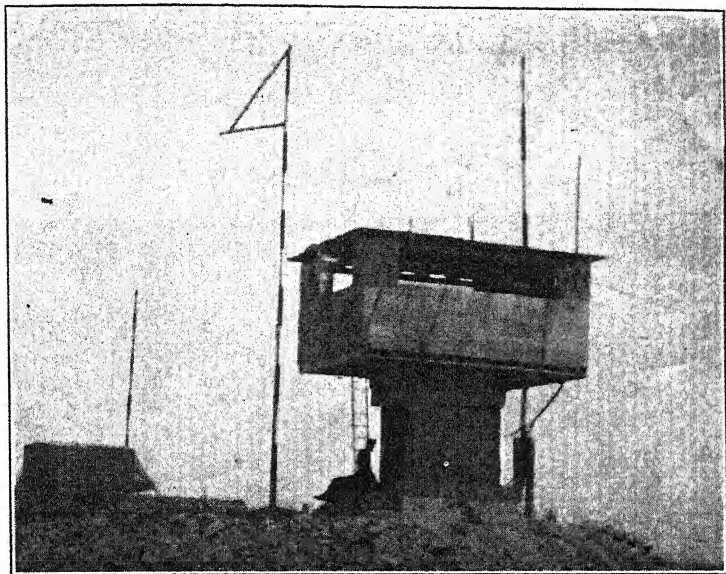


PLATE 63.—CONTROL TOWER

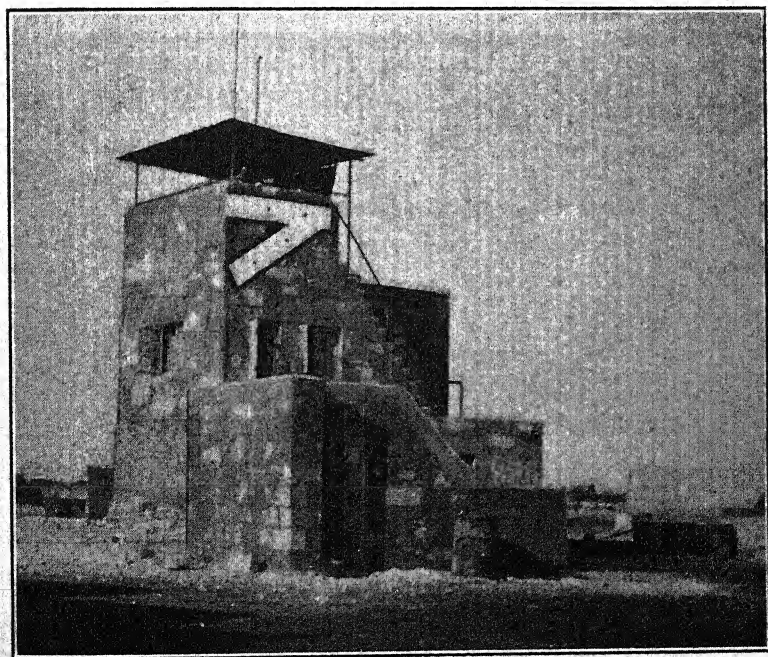


PLATE 64.—CONTROL TOWER

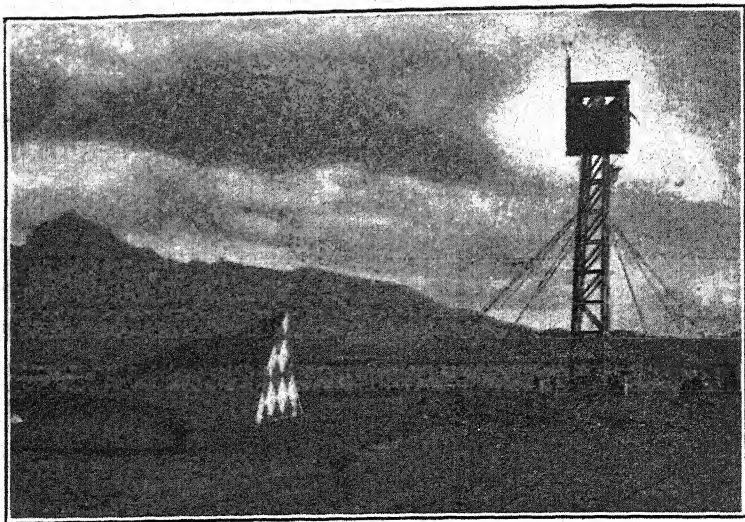


PLATE 65.—U.S. CONTROL TOWER AND WIND VANE  
SITED BETWEEN TWO PARALLEL BOMBER  
RUNWAYS

**3. Meteorological offices.**—These usually form part of the control tower, but the accommodation required varies widely with the type of unit assigned to the airfield. In operational areas abroad three establishments are typical :—

- (a) *Independent forecasting unit*, consisting of four officers, seven O.Rs. and 10 to 13 W.T. operators.

For this unit an independent building is required, with :—

- (i) Forecasting station, 140 square feet.
- (ii) W.T. office, 70 square feet.
- (iii) C.O's. office, 110 square feet.
- (iv) Store, 40 square feet.
- (v) N.C.O's. 70 square feet.
- (vi) Hydrogen generator room, 30 square feet.

- (b) *Small forecasting unit*, consisting of two officers and four O.Rs.

- (c) *Reporting and distributing station*, with three O.Rs.

All meteorological stations require access to a flat roof for setting off balloons and for the use of a theodolite. It is desirable that they should be incorporated in the control building or housed in a special structure in the immediate vicinity.

## SECTION 157.—BOMBER UNITS

1. The accommodation required by medium and heavy bomber formations operating from bases overseas is governed primarily by climatic conditions and by the appropriate standard of permanence required.

2. Buildings to ensure efficient servicing of intricate equipment, and facilities for transporting and handling heavy tonnages are of special importance.

3. The first call for hutted accommodation is likely to be for the services echelon and the repair and salvage unit.

#### 4. Services echelon

- (a) Armoury hut for small bomb-containers, which require delicate setting of fuzes in good light.
- (b) Armoury hut for turret work, gun-cleaning and storage room, and a belting room.
- (c) Wireless and batteries accommodation, well-ventilated and dry. The wireless section needs good lighting, and framing on which to mount components.
- (d) Rooms for instrument and electrical gear maintenance.

#### 5. Repair and salvage unit huts

- (a) Armoury hut. Turret storage and maintenance beyond capacity of squadron armoury.
- (b) Electricians and wireless hut.
- (c) Metal-workers' and fitting hut. Forging, brazing and salt-water annealing.
- (d) Aerofoil repairs and storage. The aerofoil is stored on racks hung from roof sections. Layout must provide for delicate handling.

6. **Wing requirements.**—From these primary needs, accommodation requirements for an established bomber wing, with two squadrons, would gradually expand to some 15,000 square feet, apart from hangars. The following minimum scales are given for guidance only :—

- (a) *Operations block.*—Ops. room, 360 square feet; intelligence, 120 square feet; targets and maps, 100 square feet; C.O.'s office, 120 square feet; clerks, 200 square feet.
- (b) *Briefing block.*—Briefing room, 1,100 square feet; offices, 240 square feet; maps, 150 square feet; clerks, 480 square feet; buffet, 150 square feet.
- (c) *Miscellaneous*

	Sq. ft.
Workshops ... ..	1,250
Armoury ... ..	2,050
Equipment store ... ..	5,000
Metal workshops ... ..	1,420
Detonator stores ... ..	1,500
Pyrotechnics ... ..	250

Also control tower and signals.

- (d) *Power plant* requirements would be about 20 k.v.a. to carry the following loads :—

Signals, 5 k.v.a. ; workshops, 7 k.v.a. ; lighting, including runways, 5 k.v.a. ; with standby plant as resources allow.

One T.1 Bellman hangar (for medium bomber) or one T.2 hangar (for heavy bomber) for the wing, and one for the repair and salvage unit.

- (e) *Administrative offices* may be required for each squadron on the basis of a squadron and flight block, 1,800 square feet. Each additional flight would need 600 square feet.

## SECTION 158.—MAINTENANCE UNITS

1. Maintenance units cover a wide range of activities and represent heavy requirements in storage, technical and administrative accommodation, at base or on L.-of-C.

In general, the demands for building and facilities conform closely to ordnance standards, but there are special factors which should be understood by engineers responsible for provision, by means of new structures or by adaptation of old. Planning and reconnaissance—and particularly where there may be competition between different services for the same buildings in captured territory—call for a good general knowledge of services to be performed.

2. Accommodation required for the forward repair units of any particular force will be laid down by the command. Representative types of maintenance unit are as follows :—

(a) *Storage and issue*

Explosive holding depots.  
Equipment holding depots.

(b) *Engineering and repairs*

Engine repair section (E.R.S.).  
General engineering section (G.E.S.).  
Signal repair section (S.R.S.).  
M.T. repair section (M.T.R.S.), including salvage.  
Aircraft repair section (A.R.S.) including salvage.

(c) *Miscellaneous*

Aircraft repair unit (A.R.U.).  
Advanced aircraft depot (A.A.D.).  
Aircraft erection units (A.E.U.).

3. Air ammunition parks, repair and salvage units, and air stores parks call for little accommodation.

4. The broad differences between accommodation demands for the storage and the engineering units are :—

- (a) Main store-holding units, whether for equipment or explosives, need an integral group of buildings and dumps, capable of protection against theft and sabotage, with dispersal governed by relevant fire, explosion and C.W. risks. Good rail and road communications are obviously of great importance.

- (b) Repair and engineering units need, primarily, power supply, good road and rail connections, and light buildings, not necessarily closely grouped. The aircraft repair section must be close to runway and servicing facilities, and will require extensive hard standings for work on dispersed aircraft or on aircraft outside the hangars.

**5. Explosive holding depots.**—These may carry ammunition, pyrotechnics, P.O.L. and C.W. stores, combined or in separate groups. Requirements are closely comparable to those of ordnance. A few special factors for consideration are :—

- (a) Tail units, incendiaries, pyrotechnics and C.W. stores, need good protection against the weather, and the last-named, good ventilation. Technical buildings, such as laboratories, workshops, belting sheds, and accommodation for the Aeronautical Inspection Department will be required.
- (b) High octane spirit demands better protection from sun-heat than M.T. petrol because of its high volatility and lead content. If this spirit goes off grade, adverse results would be serious.
- (c) Bombs of most patterns can take rougher treatment than shells, and, being commonly much heavier, need strongly constructed floors, when conditions allow the erection of sheds or construction of hardstandings.
- (d) A balanced explosive holding unit, of 10,000 tons, without P.O.L., will require 150,000/200,000 square feet of storage accommodation in 50 or 60 detached structures, of which the majority are walled.
- (e) 10,000 tons of aviation fuel, in drums and tins, and of oils, would require pits and hardstandings, with sun and rain cover, amounting to about 500,000 square feet.

For guidance, apart from any particular operation for which specific standards would be laid down, floor space requirements may be indicated as follows, in square feet per ton :—Bombs, 15 ; C.W. stores, 20 ; pyrotechnics, 12 ; S.A.A., 10.

**6. Equipment holding depots.**—A base unit is likely to require 300,000–350,000 square feet of covered accommodation, for holding all categories of R.A.F. stores. These may number over 300,000 different items, technical and non-technical, including airframes, aero-engines, armament, M.T., marine craft, turrets, W.T. and electrical gear, instruments, materials (metals, special timber, dopes, etc.), tools, barrack equipment and clothing.

Advanced holding units, or depots incorporated with an engineering unit, are likely to need 150,000 square feet of covered accommodation, when circumstances allow.

The requirements of these depots can be met, almost entirely, by standard army sheds and huts ; but adaptation of existing buildings is also a common operational call.

**7. Repair units.**—The functions of a repair unit, engaged upon salvage repair, testing and despatch of aircraft and components, are performed by five sections, grouped variously according to the facilities available.

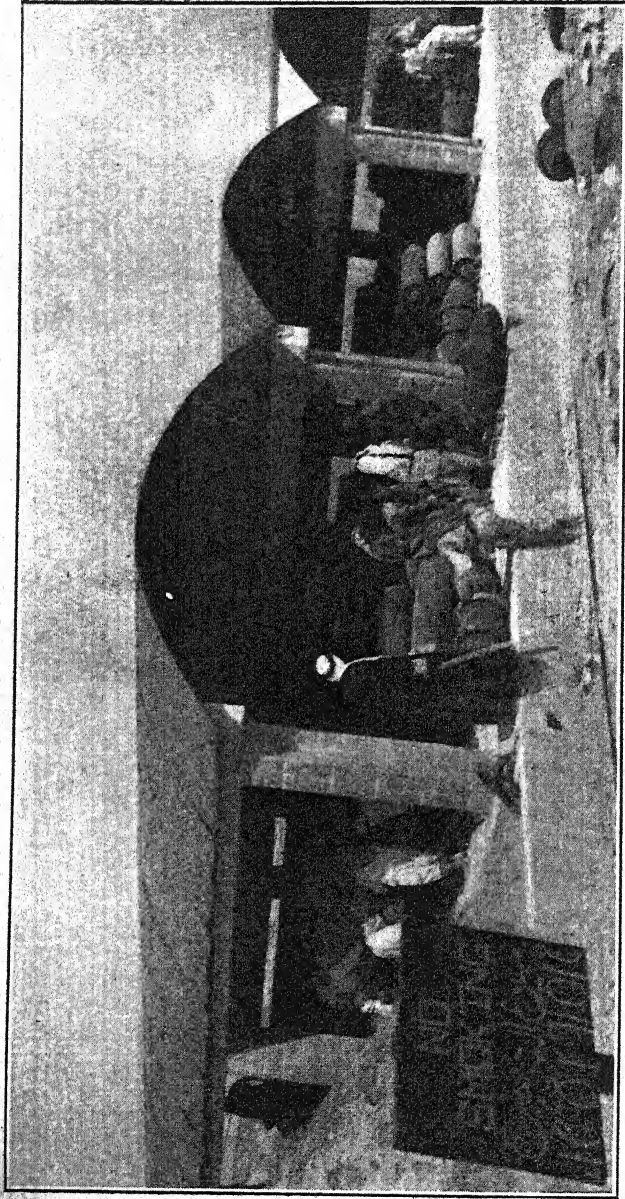


PLATE 66.—BOMB SHEDS IN SEMI-ARID COUNTRY

Aircraft and engine repair sections are commonly separate, the A.R.S. needing to be near a runway, and the E.R.S. and other sections being located advantageously at a distance from the dust and bombing risks associated with an airfield.

A unit combining all functions will require between 400,000 and 500,000 square feet of covered accommodation.

**8. Engine repair section.**—The layout provides for :—

- (a) Stripping unserviceable engines.
- (b) Cleaning.
- (c) Viewing.
- (d) Rectification.
- (e) Erection.
- (f) Testing (at benches outside the covered area).

Accommodation for 100 engines per month : assume 30,000–40,000 square feet. Wide span shedding is not essential. Floors should be of strong construction. Dust elimination is important.

**9. General engineering section.**—A full section serving an A.R.S., E.R.S., S.R.S., and M.T.R.S. would require shops, stores and offices totalling about 80,000 square feet, including certain specialist shops which are of general service. The principal branches are propeller shops (15,000 square feet), armament repairs (9,000), turret repairs (5,000), parachute and safety equipment section (3,000), machine and fitters' shop (20,000), metal workers (20,000) and chrome plating (3,000).

Some shops need special internal equipment such as the propeller repair section with heat-treatment baths and blade-balancing bay.

**10. Signal repair section.**—Accommodation for R.T. and W.T. repairs, experimental work, installation and test shops at a base M.U. (maintenance unit) would total about 10,000–15,000 square feet in well-constructed buildings.

**11. M.T. repair section.**—Air force requirements do not present any special features.

**12. Aircraft repair section.**—This section, of variable capacity and type, needs accommodation upon an airfield for the following branches of work :—

- (a) Salvage and recovery.
- (b) Fuselage repairs.
- (c) Plane repairs.
- (d) Component repairs.
- (e) Test and despatch section.

Requirements in hangars and sheds, and in hardstandings, for outdoor work, vary greatly under different climatic conditions. Covered accommodation for dealing with 100 fighter aircraft per month may exceed 100,000 square feet in a moderate climate.

An aircraft erection unit, either separately or as part of an aircraft repair section, assembles and tests cased aircraft (such as short range single-engine types) arriving abroad by sea.

## SECTION 159.—STANDARD SHEDS AND HUTS

1. All significant demands for covered accommodation can be met adequately by the standard types of army sheds and huts, which are tabulated in Table XVI below :—

Table XVI.—Standard types of hut

<i>Name of Type</i>	<i>Form</i>	<i>Span ft.</i>	<i>Normal length</i>	<i>Area sq. ft.</i>	<i>General</i>
High Marston	Vertical sides	45	200 ft.	9,000	One sliding door each end and one in each side. Crane gantry, 10 or 20 tons.
Low Marston	Vertical sides	45	200 ft.	9,000	Doors as above. No gantry.
Romney	Semi-circular	35	96 ft.	3,360	One sliding door at each end. 24 dead lights and four ventilators.
Semi-Romney	Semi-circular	35	96 ft.	3,360	Without gables. Canvas-covered.
Nissen	Semi-circular	24	66 ft. 5½ ins.	1,597	10 dormer windows.
Nissen	Semi-circular	16	36 ft. 3 ins.	580	Four dormer windows.
Nissen	Semi-circular	16	36 ft. 3 ins.	580	End windows only.

2. When these sheds or huts are available, provision of cover will be rapid, but there remains the heavier task of drainage, concrete flooring, construction of hardstandings and access tracks for aircraft and M.T., apart from the internal equipment of sheds.

Floors and all-weather surfacing for one base repair unit may approximate 150,000 square yards.

## SECTION 160.—HANGARS

1. Five standard types of prefabricated hangars are in common service although it is probable that only three types will be used in any one theatre. These types are shown in Table XVII below :—

Table XVII.—Standard types of hangar

<i>Type</i>	<i>Standard Length ft.</i>	<i>Width ft.</i>	<i>Area sq. ft.</i>	<i>Height of entrance ft.</i>	<i>Lorry Loads 3-ton</i>	<i>Supply responsibility</i>
Merton	40	47-18	1,300	17	1 (with trailer)	R.A.F.
Bessoneau	78	65	5,070	17	3 (with long trailers)	R.A.F. or Army
Over-bliester	45	86	3,870	19	10	R.A.F.
Bellman and T.1	175	95	16,625	17 or 25	67	R.A.F.
T.2	240	114	27,360	25½	134	R.A.F.

2. Erection of hangars in operational areas is an army responsibility. It may also be necessary to build new hangars, using local trusses and masonry, when standard types are short, or for economy of transport. Enemy hangars are commonly too badly damaged to allow profitable reconstruction, though useful as sheltered hardstandings. In Italian hangars, asbestos sheeting is much used and this shatters easily.

3. **Merton.**—This hangar is constructed of tubular steel framework, in sections joined by flange plates and bolts, and covered with canvas. The floor is 47 feet wide at the entrance by 40 feet long, but a space of 100 feet by 93 feet is required if the whole of the camouflage sections are attached.

The entrance of the hangar is closed by two canvas curtains, operated by winch and cable. An engine-changing hoist, with a 30-cwt. pulley block and tackle is provided. The hangar frame is secured to the ground by pickets.

4. **Bessoneau.**—This is a timber-framed portable hangar, clad with waterproof canvas. The trusses are built up of short lengths of timber, spaced at 13 feet centres and carried on timber-frame buttress pillars. All members are bolted and plated. The hangar entrance is covered by canvas curtains, fixed to rollers, sliding on steel track. *See Plate 67.*

5. **Over-blister.**—This easily transportable and quickly erected hangar is comprised of light steel-frame sections, arched, clad with C.G.I. Ground levelling can be comparatively rough. Height to crown of the arch is approximately 20 feet and the span between uprights 65 feet. The total weight is 15 tons and the heaviest piece under 200 lb. An experienced squad of 10 men can erect in five days. A floor of 100 feet long has to be cleared if domed canvas curtains are fitted at both ends. (*See Plate 67.*)

6. **Bellman and T.1.**—This important type, of useful dimensions, can be loaded into rail wagons or three-ton lorries with minimum loading facilities. It is of all-steel welded construction, covered with C.G.I. Doors can be either of a steel-framed pattern of unit construction or of heavy canvas, with tubular steel stiffeners. (*See Plate 68.*)

7. **T.2 type** hangar is of similar construction to the Bellman, but is of greater width and height to serve heavy bombers. It is good practice to increase the floor area and serviceability of Bellman and T.2 type hangars by constructing lean-to buildings along either side, the bottom courses of sheeting being omitted to provide open connection. These bays are useful for subsidiary purposes, for housing shelves, work benches, racking and minor equipment. Concreting or cement stabilization of floors is better than a specification involving bitumen.

8. "Nose hangars", to give shelter for work on aircraft engines, are of two broad types :—

- (a) Substantial structures to give cover for working simultaneously on four bomber engines.
- (b) Light portable nose hangars to be used for a single engine.

Shelter for work on engines is commonly provided in operational theatres by improvised methods, to suit local climate and resources. Adequate hardstandings are of first importance.

9. American types of portable hangar.—Four types call for reference :—

- (a) *Butler hangar*.—This type, large enough for two or three bombers, has been widely used by the U.S. Air Force. It comprises a three-hinged steel frame arch, with a suspended canvas cover. Central height 35 feet, width at ground level 130 feet, and normally 160 feet in length. The total weight is 54 tons. Design is strong enough to withstand pressure of earth revetment up to 10 feet in height along the sides, for blast protection. (See Plate 69.)

A new type of Butler hangar has been produced, with C.G.I. roof and canvas ends only. Lighter members are employed and the arches cannot be used for suspending tackle to carry a load in excess of 500 lb.

Additional clearance, vertical and horizontal, is sometimes provided by erection upon buttress-type concrete footings.

- (b) *Armco-Steelox*.—A 2-hinged lattice web steel arch covered with steel roof sheets, 150 feet wide at ground level and 37 feet maximum height. Weight, 60 tons for length of 160 feet.
- (c) *Dorst "airplane tent"*.—A canvas tent carried by wire rope and steel pipe poles. Width, 120 feet. Weight, 5.3 tons for length of 92½ feet.
- (d) *Luria "catenary tent"*.—A canvas tent supported by wire rope and collapsible metal poles. Width, 130 feet. Weight, 22 tons for length of 160 feet.

#### SECTION 161.—PENS

1. Some thousands of aircraft pens have been constructed in operational areas abroad, by the enemy and ourselves, with remarkable diversity of type, grouping, size, numbers and method of construction. Protection of aircraft and personnel is the primary aim, but pen walls also serve a useful purpose by providing shelter around hardstandings for maintenance work. Pens may be improved by building a cantilever roof at the rear, for protection from sun or rain, and a gantry for engine removal.

2. The demand for pens varies directly with the danger of enemy bombing and the limitations of dispersal. A policy of intensive pen construction will be adopted only in such circumstances as prevailed during 1941/3 in Malta, with its restricted dispersal, repeated attacks from the air, congestion of aircraft, and good natural resources for construction in stone.

3. Different types of pen are as follows :—

- (a) *Surface pens*, with standings at ground level (normal type for bombers and fighters). Sometimes splinter-proof covered (fighters). (See Plates 73 and 74.)

- (b) Semi-sunken pens, with standings a few feet below ground-level and served by an easy ramp. (Fighters or bombers.) (See Plate 77.)
- (c) Sunken pens, with aircraft wholly below ground; either camouflaged or splinter-proof covered. (Fighters, only.)

4. Typical dimensions are :—

Type of Aircraft	Width. Feet	Depth. Feet	Height. Feet
Fighters (2) or light bombers (1)	90	60	10-12
Medium bombers ... ..	104	85	12-14
Heavy bombers ... ..	130	85	14-16

The steepest gradient for ramps for sunken fighter pens is 1 in 15; and for semi-sunken bomber pens, 1 in 30.

5. Sandbag walling will be found to be the simplest and quickest method of constructing surface pens. The number of sandbags used will be approximate :—

	Solid walling	Walls filled with rubble
Fighters ... ..	17,500	13,000
Medium bombers ... ..	30,000	20,000

For more durable work, use of sandbags filled with cement-stabilized or bitumenized sandy-soil is good practice. Examples of sandbag pens are given in Plates 79 and 80.

6. In operational areas, use is made of old oil-drums, petrol tins, C.G.I. with any type of revetting poles, stone-walling, mud bricks, etc., according to resources.

7. Under static conditions, earth-traversed masonry walls are commonly the most satisfactory type, but comprise big tasks and are rarely justified. Quantities involved in a single heavy bomber pen include 200 cubic yards in excavation and concrete foundations, 600 cubic yards in masonry, and 2,000 cubic yards in earthwork. The hardstanding requires 1,250 square yards of paving.

8. Pens with splinter-proof cover in reinforced concrete have been commonly built, on surface or sunk, to provide full or partial protection for fighter aircraft.

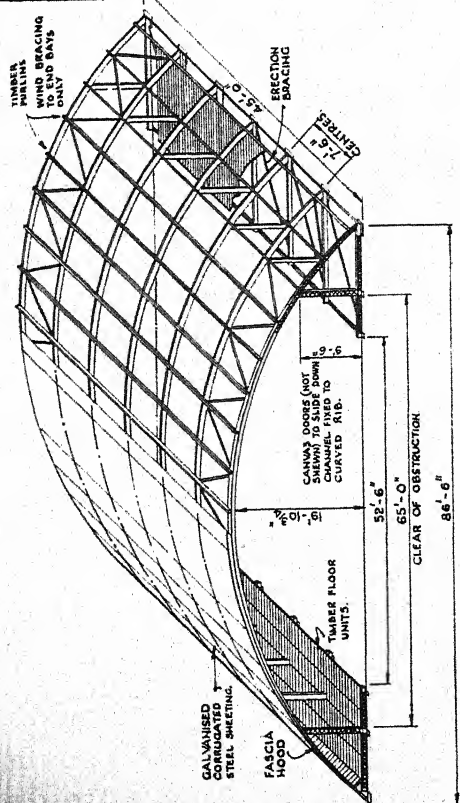
Sunken pens are most suitable for accommodating fighters assembled in readiness near the runway, when enemy activity justified special precautions to protect non-dispersed aircraft. This type has been constructed usually with splinter-proof protection, but also with camouflage cover only.

All these types have been built in considerable numbers and some depart from the accepted practice. Double pens should open in different directions, unless given additional blast-wall protection, and no triple pens should be constructed.

In countries where strong winds are prevalent, aircraft are secured by picketing blocks, built into the hardstandings.

NOTE - NORMAL LENGTH OF HANGAR  
G BAYS OF 13 FEET = 78'0"

BESSONNEAU HANGAR.



PROJECTED ELEVATION  
SCALE 16 FEET TO 1 INCH.  
OVER BLISTER HANGAR.

PLATE 67.—FIELD HANGARS—OVER BLISTER AND BESSONTEAU TYPES

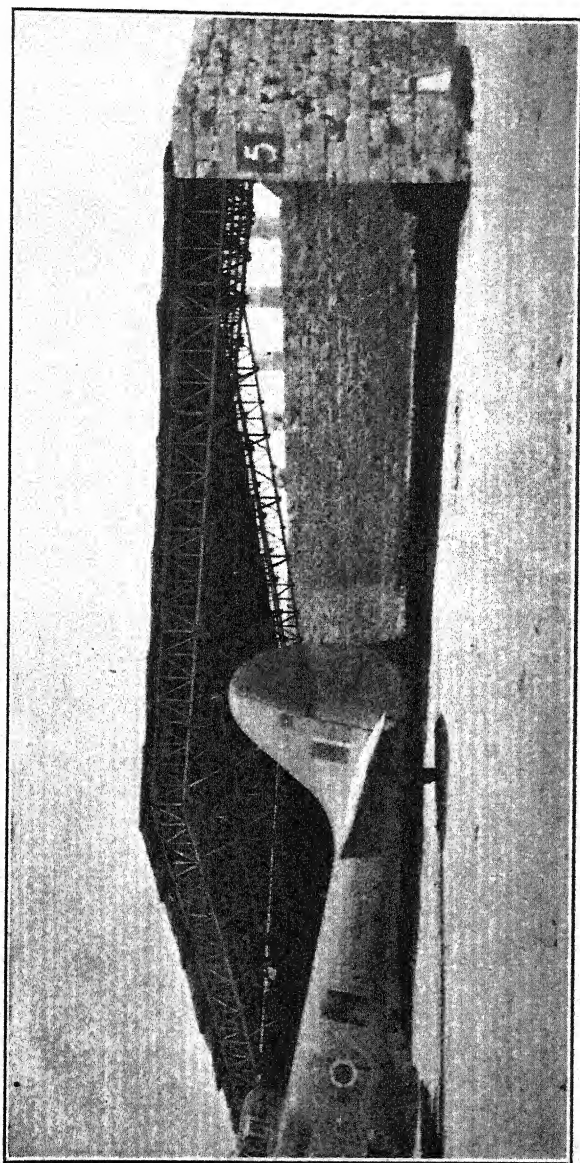
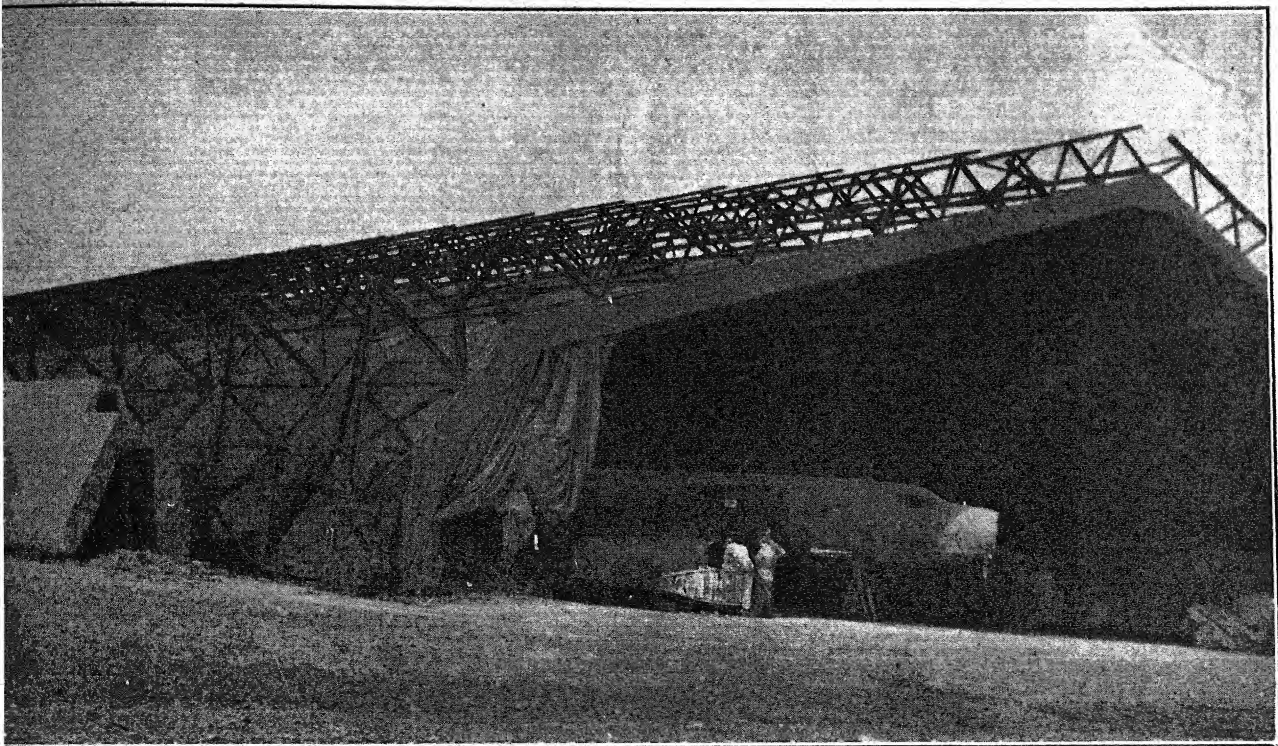


PLATE 68.—BELLMAN HANGAR ROOF WITH MASONRY WALLS



69.—U.S. BUTLER HANGAR—3-HINGED STEEL FRAME ARCH WITH CANVAS COVER SUSPENDED

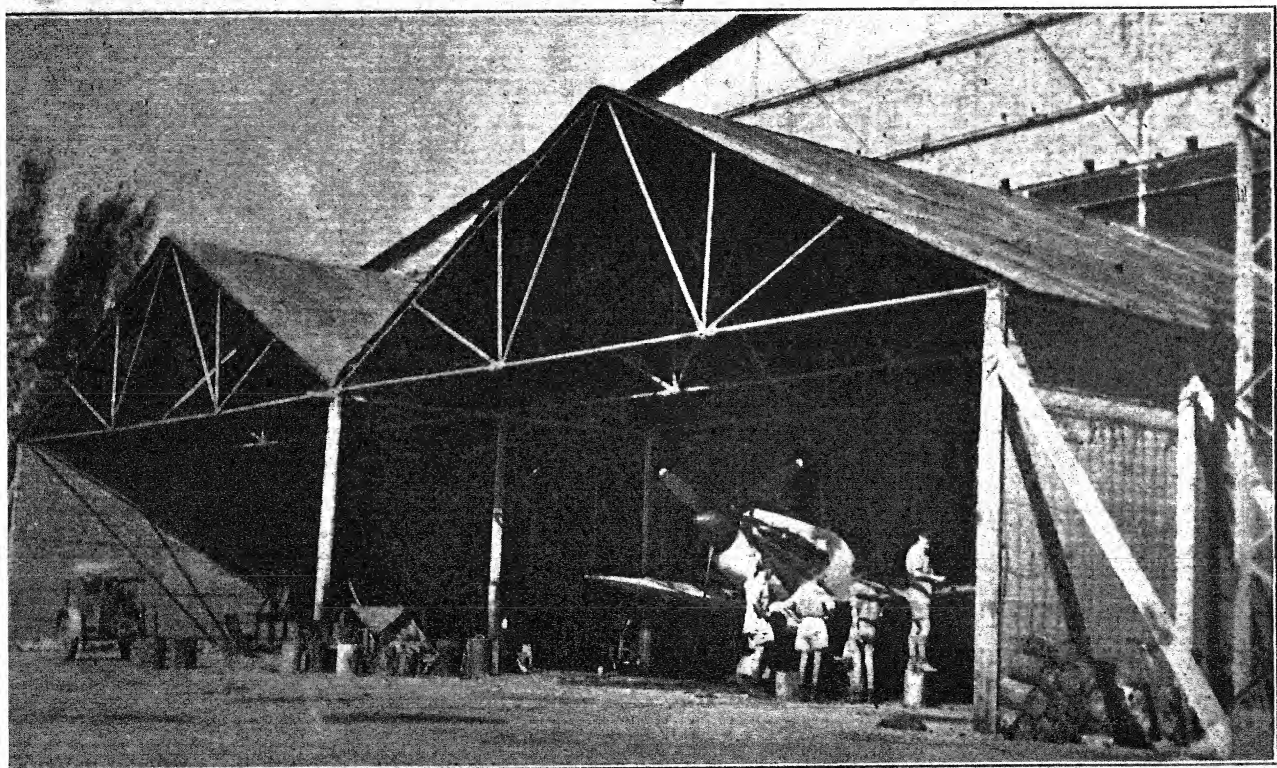


PLATE 70.—SMALL HANGAR FROM SALVAGED MATERIALS. TRIPOLI

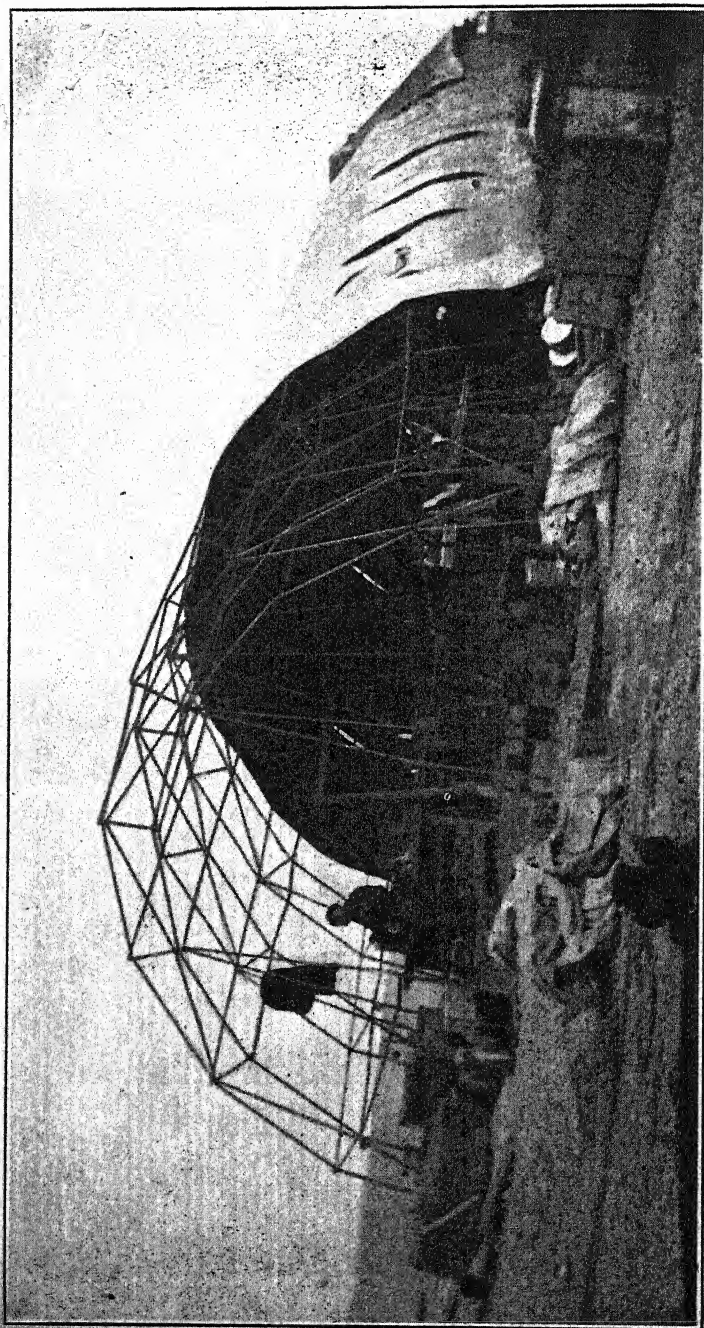


PLATE 71.—WORKSHOP OF R.A.F. REPAIR AND SALVAGE UNIT USED IN MOBILE OPERATIONS

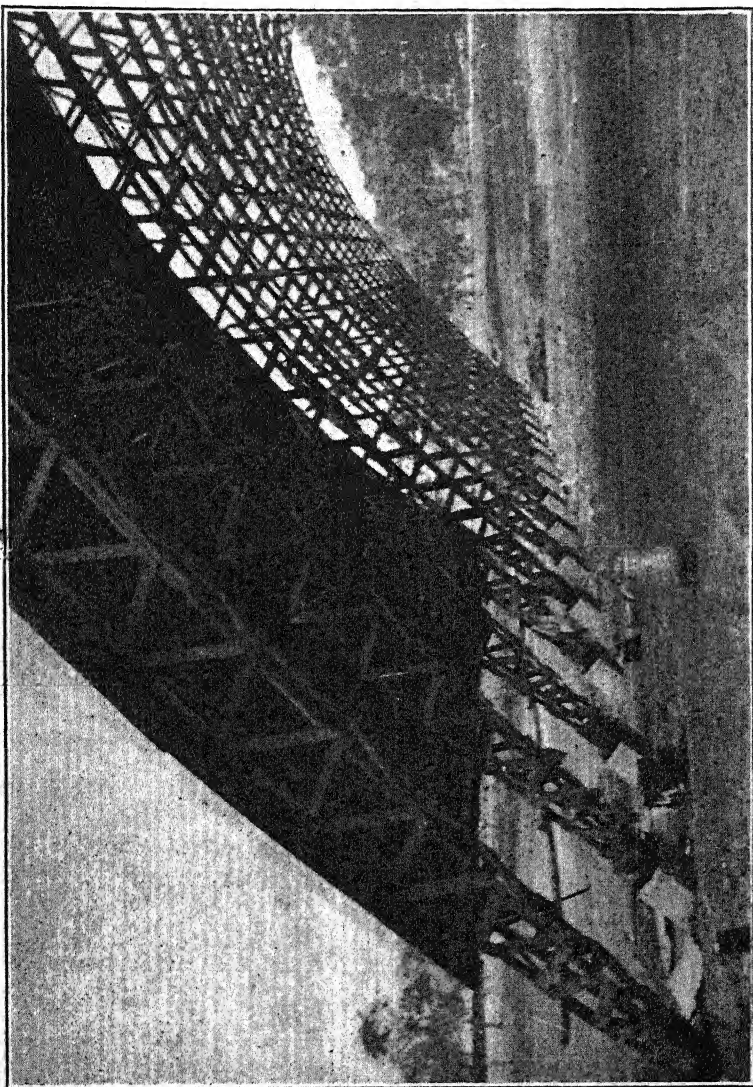


PLATE 72.—IMPROVISED LATTICE-GIRDER FRAME HANGAR. SOUTHERN PACIFIC



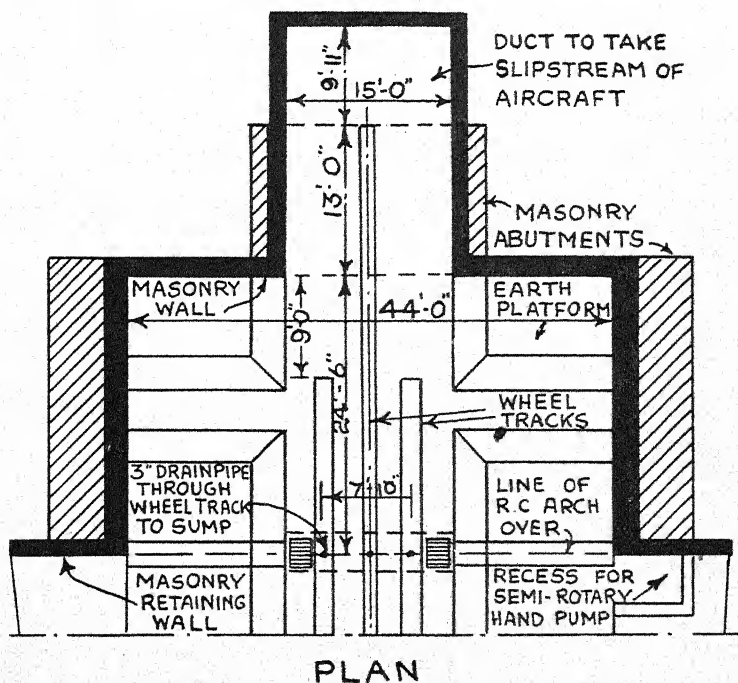
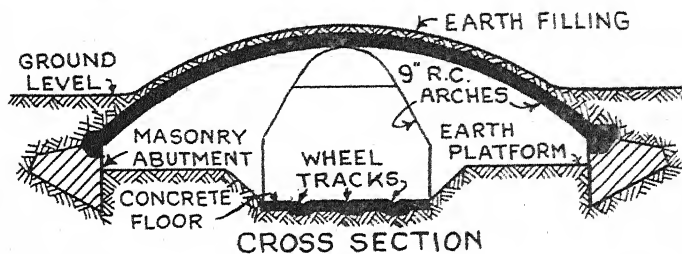
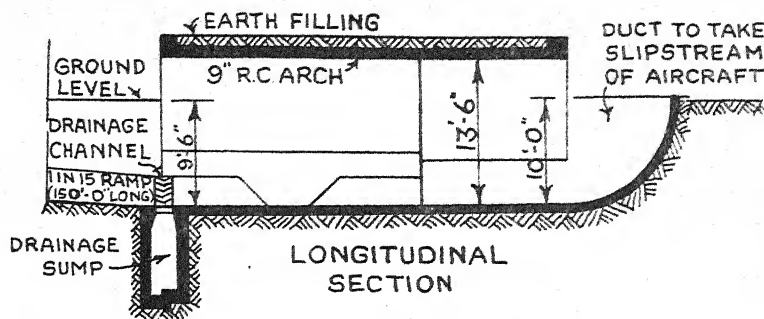
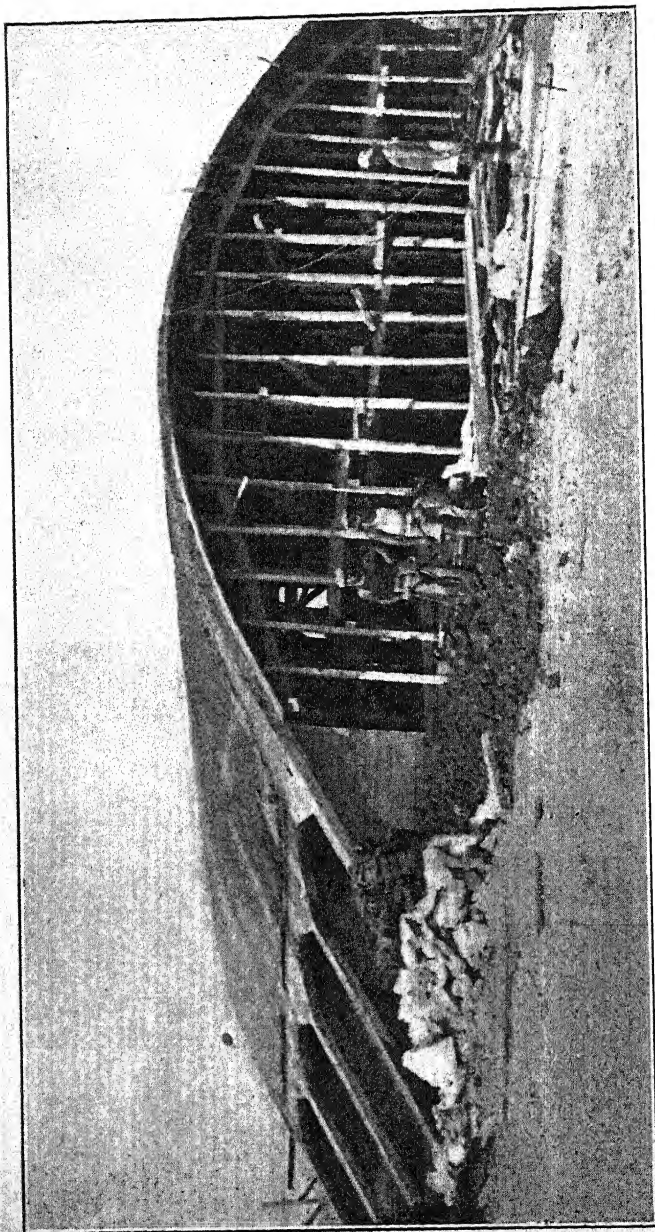


PLATE 74.—AIRCRAFT PENS—COVERED TYPE



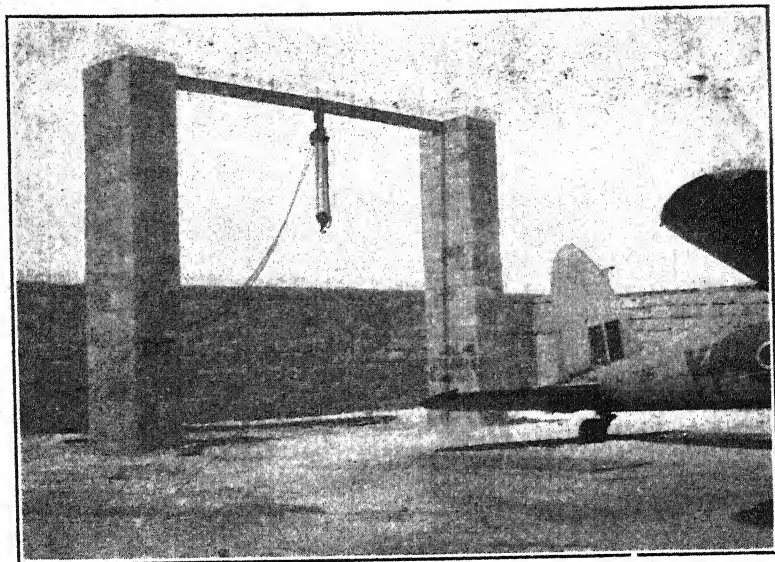


PLATE 76.—MASONRY FIGHTER PEN. MALTA

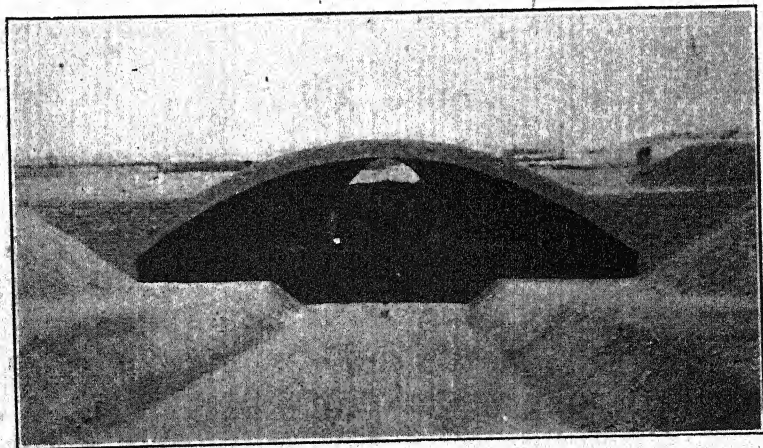


PLATE 77.—SEMI-SUNKEN FIGHTER PEN. PALESTINE

9. **Technical vehicles.**—Under certain conditions, the construction of sand-bag pens, for R.A.F. technical vehicles (on ground level or semi-sunk), is given priority over the protection of aircraft. (See Plate 81.)

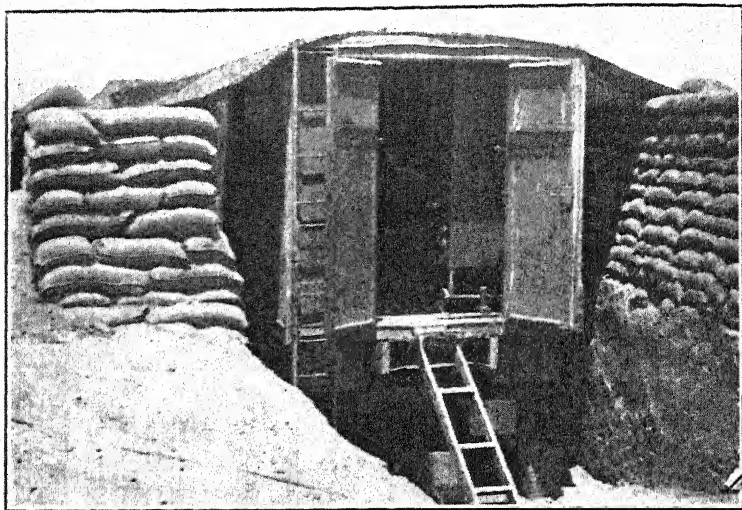


PLATE 81.—R.A.F. TECHNICAL VEHICLE—HASTY PROTECTION

10. **Totally enclosed pens.**—In areas of intense enemy bombardment, frontal protection of fighter aircraft in pens has often been provided by an encircling wing wall.

The Japanese in the Pacific have adopted a scheme using trucks which are run on metal rail tracks laid across the pen opening, like hangar doors.

The trucks are built up and filled with sand and run back and forth as required, giving full lateral protection. There are risks of aircraft being temporarily imprisoned, upon damage to tracks or trucks, but the chances are that bomb fragments affecting these movable revetments would have otherwise damaged the aircraft.

#### SECTION 162.—OPERATIONAL TRAINING UNITS

1. Although training units are located at a distance from any active area of operations, where little enemy interference is to be expected, construction of airfields and buildings is sometimes a sapper task. A broad study of their special features is educational from the standpoint of Air Force technical requirements and activities in general.

These units train crews, with previous flying experience, in operational practice with all types of aircraft.

2. O.T.U.s. may be broadly grouped as follows :—

- (a) Fighter.
- (b) Fighter recce. and army co-operative.
- (c) Light bomber.
- (d) Medium bomber and heavy bomber.
- (e) General reconnaissance.

These groups are again divided into types of aircraft, of which one or two will be used at a single station.

3. The buildings required will be largely of a specialist nature, for which detailed working drawings will be provided by commands. Improvisation with existing buildings rarely allows adequate standards to be attained.

The whole layout must be dominated by demands for efficiency of procedure and for economy of time. Wide dispersal is undesirable. A diagrammatic layout of an operational training unit is shown in Plate 82.

If squares or rectangular areas are not practicable, at least two runways must be constructed, with taxi-tracks laid out to ensure rapid circulation.

Each airfield will need an auxiliary field with considerable facilities varying with local conditions.

4. Provision must be made for the efficient inter-relationship between flight-ways and the following areas :—

- (a) Ground training.
- (b) Flying training flight.
- (c) Maintenance and servicing.
- (d) Station administration buildings.
- (e) Domestic camp.

5. **Ground training area.**—This section, under the chief ground instructor is divided into five training sub-stations, directed by senior instructors, as follows :—

- (a) Navigation.
- (b) Signals.
- (c) Armament.
- (d) Photographic.
- (e) Intelligence.

All theoretical and synthetic instruction is given in this area, which should be sited away from the noisier sections of the airfield.

6. **Flight area.**—The correct siting and ample design of the control tower building, from which the chief flying instructor watches his pupils in action, are of first importance. Flight offices, the air-crew rest room, and briefing room will be in close proximity.

7. **Maintenance and servicing areas.**—Maintenance provision must be liberal, for total flying hours are heavy. Minor inspections

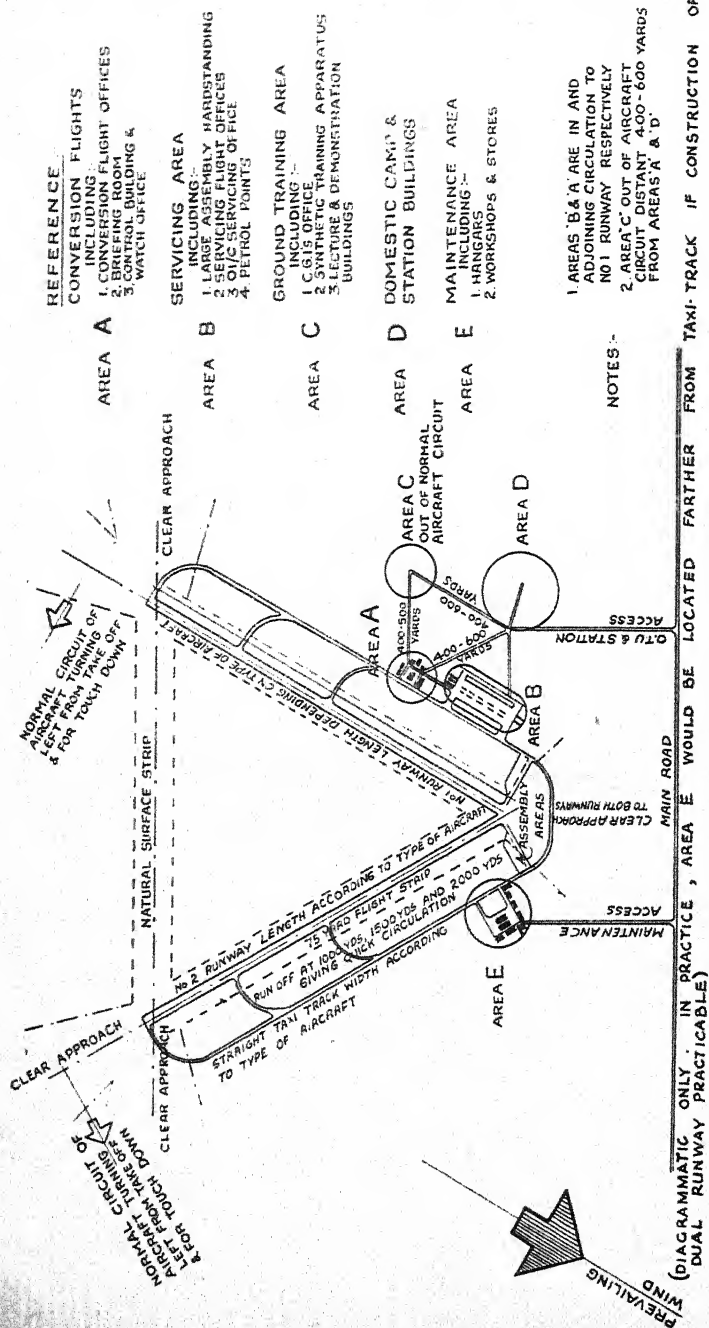


PLATE 82.—OPERATIONAL TRAINING UNIT—DIAGRAMMATIC AIRFIELD LAYOUT

(DIAGRAMMATIC ONLY. IN PRACTICE, AREA E WOULD BE LOCATED FARTHER FROM TAXI-TRACK IF CONSTRUCTION OF DUAL RUNWAY PRACTICABLE)

and repairs are carried out in the servicing area and "majors" are passed to the maintenance wing, provided with hangars, workshops, stores and offices.

**8. Technical demands.**—The most important and common technical demands are briefly enumerated below :—

- (a) *Hunt range or recognition trainer.*—Used for training in estimation of the distance of a moving target. A feature of construction is a large travelling mirror, by means of which small suspended model aircraft are made to appear approaching or receding from the pupils.
- (b) *Air Ministry bomber trainer.*—For the training of bomber crews under operational conditions. Target scenes are projected on to the floor, 10 feet above which the bomb-aimer lies on a small platform where all instruments are fitted.
- (c) *Harwell trainer.*—A hut fitted up with a number of cubicles, representing sections of an aircraft, for the training of wireless operators.
- (d) *Link trainer.*—For synthetic flying training. Pupils are instructed in the use of beam approach, flying by ground based R.T., etc.; equipment is extremely delicate and needs good housing.
- (e) *Tactical floor.*—The floor is a model sea-scape on which are placed miniature harbours, ships, lighthouses, etc., for training in navigation, wireless "ops." and ship recognition. Cubicles are ranged at each end of the floor to represent the interior of aircraft. Crews work therefrom, directed by W.T. from a control room behind the cubicles.
- (f) *Dead reckoning instructor.*—For training in dead reckoning navigation.
- (g) *Navigation and astrodome building.*—This has a domed roof representing the sky—stars and constellations being shown at will by small electric bulbs.
- (h) *Airmanship hall or crew procedure centre.*—For housing instructional fuselages, used for training crews in all drills. All the services—hydraulic, electrical and pneumatic—work normally. Parachute and dinghy drills are also carried out.
- (i) *Ranges*
  - (i) Dummy bomb range, for use of light practice bombs, not more than 10 miles from airfield.
  - (ii) Live bomb range, about 10 miles from airfield. Danger zone radius, 2,000 yards.
  - (iii) Air-to-ground range may be incorporated with a turret-training range. Target area is in form of equilateral triangle, with sides of approximately 6,000 yards.
  - (iv) Air-to-air firing range, for firing at towed targets.

The above represents a typical selection of O.T.U. constructional requirements, but is not comprehensive.

### SECTION 163.—PARACHUTE PACKING AND STORAGE SHEDS

1. In the layout and design of these buildings, provision is made for the systematic circulation of parachutes, the sequence being :—

- (a) Reception and rough inspection.
- (b) Repairs if necessary.
- (c) Hanging and drying.
- (d) Packing.
- (e) Storage on racks.
- (f) Issues.

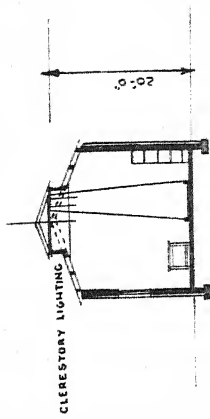
Hanging capacity must be adequate to allow the given number of parachutes to hang for at least a day per month and the table area is based on an estimate of 1 hour's work per month on each.

2. Big installations are commonly designed for special roles and do not conform to standards. A typical small unit would house one table, hangers for 18 and storage for 150 parachutes. Adaptation of existing buildings is sometimes practicable in emergency, but table construction, and temperature, light and ventilation control call for meticulous care. No risks can be accepted.

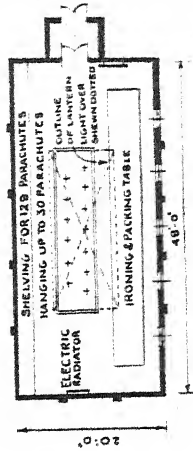
3. Certain general standards apply to all buildings :—

- (a) Suspending pulleys, 20 feet up, to give ample room for handling. Cords are laid on the floor, which is linoleum-covered.
- (b) Hooks 2 feet apart. (18 inches minimum.)
- (c) Dust and sunshine to be excluded as completely as possible.
- (d) Good ventilation and even temperature (minimum 65 degs. F.) are important.
- (e) Electric lighting is essential, "daylight bulbs" being preferable to reduce glare. Points are wanted for electric irons on packing tables.
- (f) In some countries, paraffin traps have to be installed to keep crawling insects away from storage racks.
- (g) Metal fittings coming in contact with parachutes must be "rustless."
- (h) Packing tables, 40 feet to 45 feet by 3 feet 6 inches and 2 feet 6 inches high, must have a smooth top, without any sharp edges liable to damage the parachute fabric. Surfacing materials recommended are linoleum or aircraft fabric, treated with dope.

Alternatively, a masonite or a "terazzo" polished surface can be used. With linoleum, care must be exercised to avoid cracks.

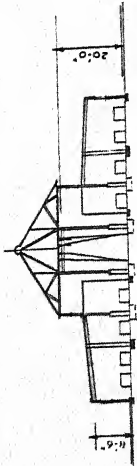


SECTION AA

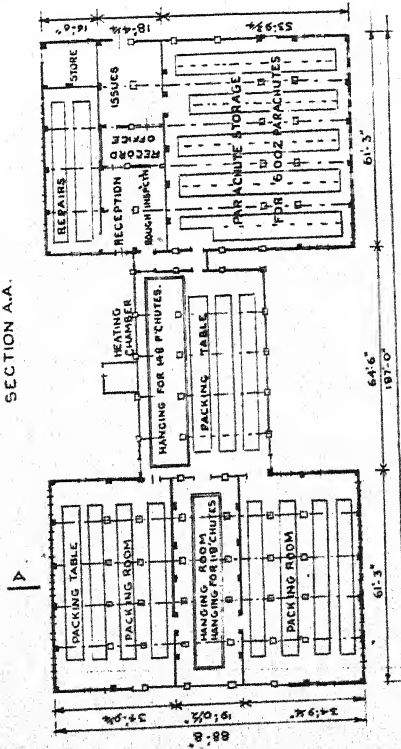


PLAN

SMALL PARACHUTE BUILDING



SECTION A.A.



PLAN

LARGE PARACHUTE BUILDING

PLATE 83.—PARACHUTE BUILDINGS, LARGE AND SMALL TYPES

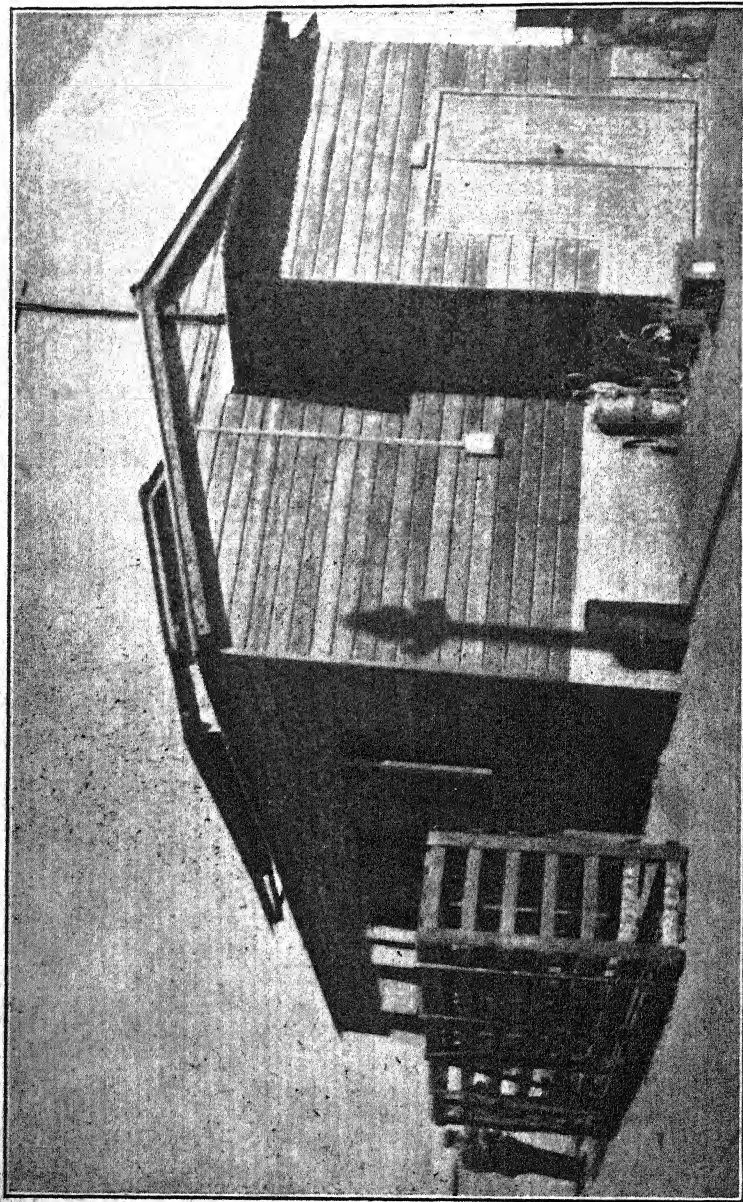


PLATE 84.—SQUADRON PARACHUTE HUT

## CHAPTER 22

## PETROL INSTALLATIONS ON AIRFIELDS

## SECTION 164.—GENERAL

1. The construction of bulk petroleum installations in major theatres of war, involving heavy work on storage sites near ports or beaches and piping systems to advanced distribution centres, is the responsibility of R.E. units under the Director of Works. Practice and principles will be found in the current engineer publication, "Construction of Petroleum Installations in the Field."

2. Engineers serving the Air Force must be fully experienced in the storage, protection and distribution of aviation spirit upon, and in the vicinity of, airfields. The maintenance of a large constant supply is a vital operation, in which R.E. services play an increasingly important part as the scope of drum storage and distribution become more limited.

In lesser theatres of war, the provision of means for the delivery of aviation spirit from port or railhead to static airfields will often be solely the responsibility of the engineers engaged in airfield construction.

## SECTION 165.—STORAGE

1. Normally, provision is made for a week's supply of aviation spirit. As a guide, the following quantities were held immediately available, during a recent desert campaign :—

Per squadron, minimum :—

Fighter, 10,000 gallons.	Medium bomber, 25,000 gallons.
Light bomber, 20,000 gallons.	Heavy bomber, 45,000 gallons.

In certain contingencies, a group of bomber airfields may require 100,000 gallons per day.

2. Initial storage, upon advanced landing grounds, will nearly always be in drums. Containers, usually 40-gallon drums, are distributed in well-dispersed and easily served dumps of about 5,000 gallons capacity. Blast protection and camouflage are commonly required, if static conditions arise. The demand for hardstandings and all-weather tracks will be governed by soil, climatic, and tactical conditions. In open reserve dumps, provision should be made for standing upright drums at an angle to keep rain-water, collecting on the top, clear of the bung hole. Dumps must be sited at a safe distance from standing aircraft.

American forces sometimes use collapsible 700-gallon synthetic rubber tanks, in plywood housing, in addition to 55-gallon (U.S.) drums.

At the earliest opportunity, barrel dumps are replaced by tank or "cistern" distributing points.

3. The storage tanks available may be any or all of the following :—

<i>Type</i>	<i>Capacity</i>		<i>Fittings</i>
	<i>Tons</i>	<i>Imperial gallons</i>	
Welded	26	8,000	20 ft. x 9 ft.
Welded	40	12,000	30 ft. x 9 ft.
Bolted	30 to 90		4-in. inlet and outlet Five sizes—4-in. inlet and outlet
Bolted	120 to 1,200	36,000 to 360,000	Four sizes—4-in. inlet 6-in. outlet

4. Installations on isolated airfields where petrol can only be delivered in drums are usually equipped for barrel decanting, as illustrated in Plate 87. The tank is equipped with a decanting trough connected through valve and filter, and is sunk into a pit, the spoil from which serves to make a ramp to the level of the decanting trough. A platform at the top of the ramp is made to accommodate up to 36 full drums. The weight of barrels on decanting is taken by the platform which is strengthened by rails, sleepers or concrete beams.

#### SECTION 166.—RAIL-TANKER DISCHARGE POINTS

1. An existing siding is taken over, or a new one constructed about 250 yards long, to provide for discharging from 20 rail-tankers. The siding should be preferably on an embankment or running along the side of a slope to facilitate gravity discharge into storage tanks. The discharge header is placed 4 feet from the rail and parallel to it. (See Plate 88.)

2. A typical header for 60,000 gallons storage will be 8 inches in diameter and have 20 branch connections for rail tankers, with a stop valve in each branch. Storage tanks with their tops at the same level will be sited to permit gravity flow, which may involve sinking them or cutting benches on the side of a slope.

3. A good fall to the site of the storage without undulations is desirable. Tee connections and valves will be fitted at the lowest point for water drainage.

4. For road tankers and pipe-fed installations, no filling header is required.

#### SECTION 167.—DRAW-OFF ARRANGEMENTS

1. At any main bulk-petrol installation, or a subsidiary fed from it by pipe-line, draw-off arrangements will be provided for :—

- (a) bowser suction,
- (b) bowser filling from a gantry, or
- (c) barrel filling.

2. If tanks are inter-connected at low level one suction pipe is provided for bowser suction ; otherwise a separate pipe is connected to each tank.

3. For bowser filling by gravity, the discharge header takes the form of an overhead gantry to allow the bowsers to stand beneath for filling with  $2\frac{1}{2}$ -inch hose. (See Plate 88.)

4. For barrel filling the layout is like a bowser-filling gantry in miniature. The piping is erected over a platform which is at the correct height for lorry loading.

5. Hardstandings and dust-free tracks are required for the service of all filling points as early as possible.

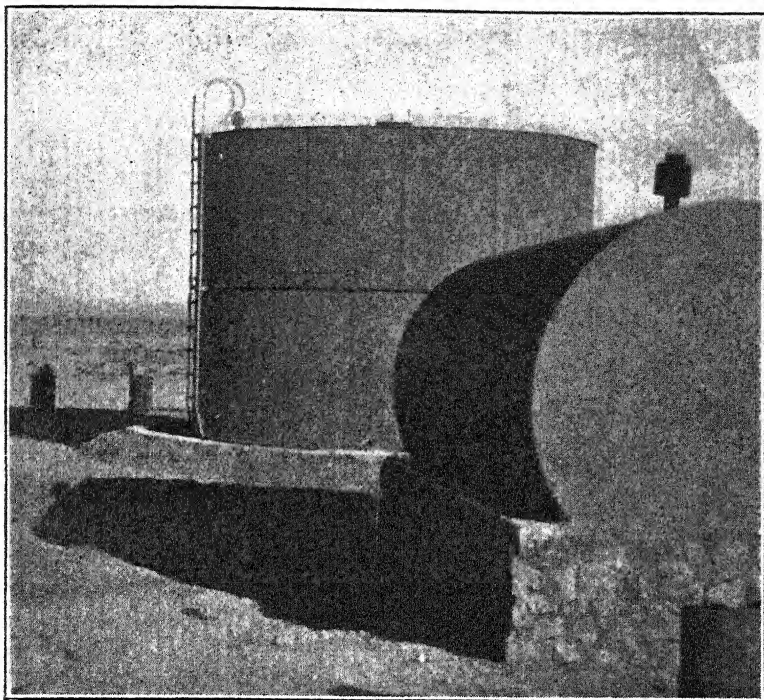


PLATE 85.—PETROL TANK STORAGE ON DESERT AIRFIELD

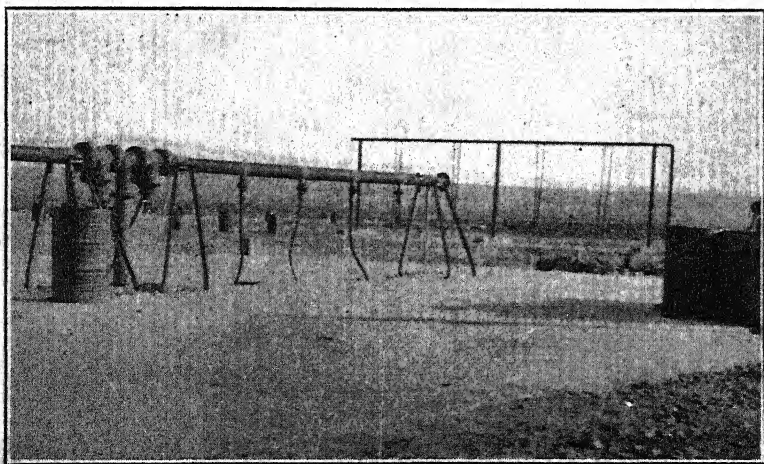


PLATE 86.—PETROL FILLING STATION FOR DRUMS  
AND BOWSERS ON DESERT AIRFIELD

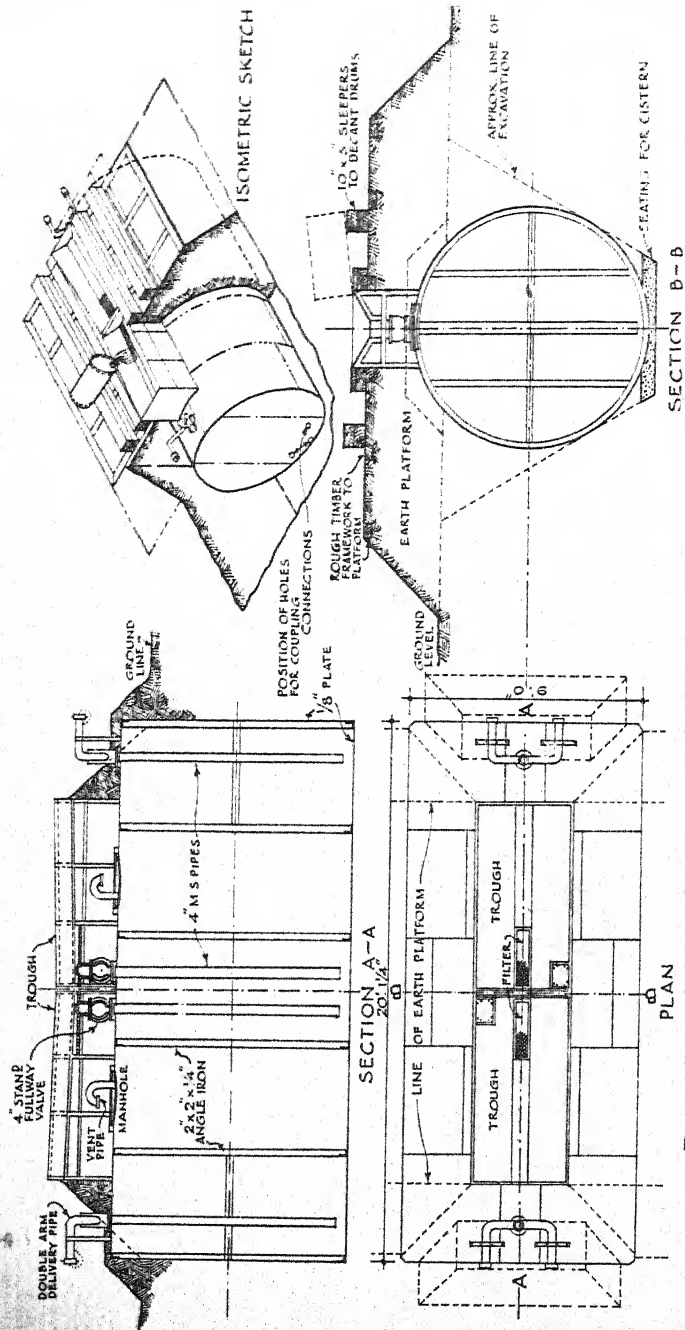


PLATE 87.—PETROL STORAGE ON SMALL STATIC AIRFIELD—26-TON TANK

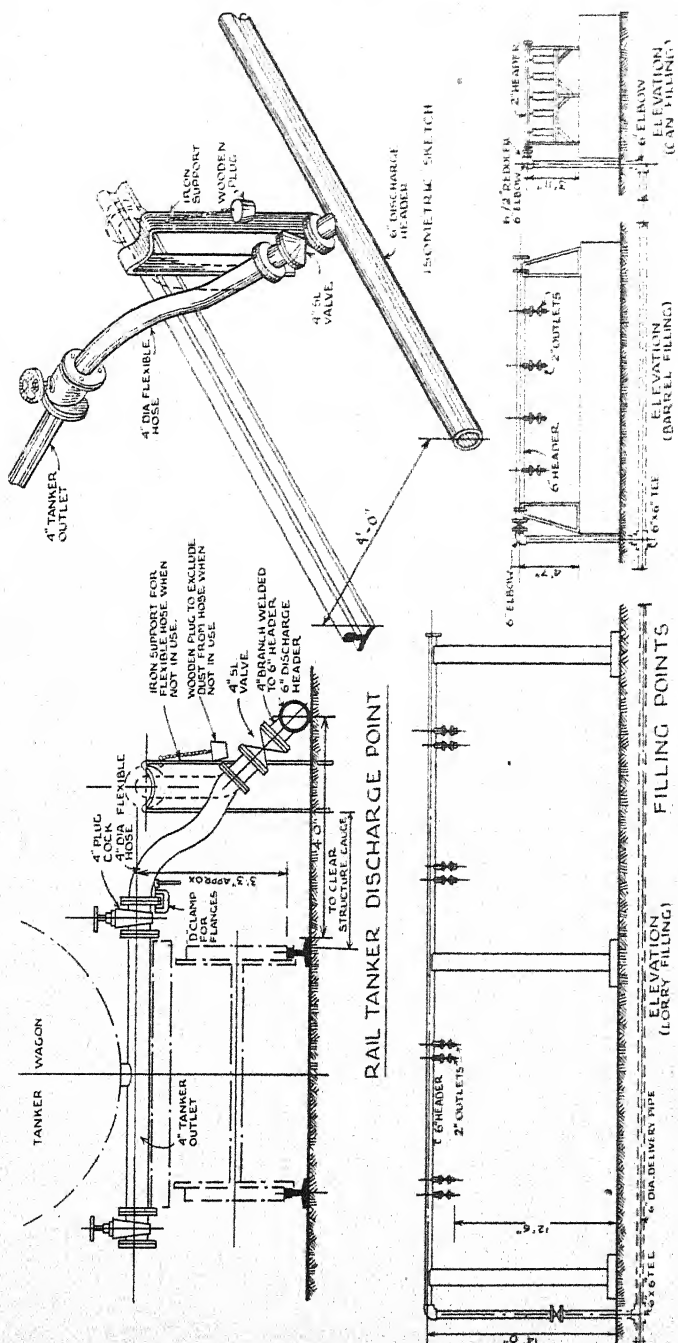


PLATE 88.—PETROL STORAGE AND DETAILS OF DISTRIBUTION

## SECTION 168.—DISTRIBUTION OF PETROL ON AIRFIELDS

Distribution on military airfields is usually by bowsters, but at staging posts and important static aerodromes it may be necessary to provide for rapid filling of aircraft direct through connections from stand-pipes on hardstandings or assembly areas.

This may involve pipe-line distribution. The line should be laid in a shallow trench, not back-filled. At road crossings the pipe should be preferably run under a culvert. When not trenched, pipe lines must be securely anchored at suitable intervals to prevent changes of alignment liable to cause slight leakage.

## SECTION 169.—TECHNICAL CONSIDERATIONS

The design and layout of petrol installations are governed by the following considerations :—

- (a) Petrol has a specific gravity of 0.73. Its vapour pressure at normal temperatures is much higher than that of water.
- (b) Petrol attacks non-synthetic rubber and certain other jointing materials.
- (c) The maximum suction lift at 110 degrees F. is 20 feet, and as the temperature increases this distance decreases rapidly to zero at 140 degrees F. Below 60 degrees F. the lift is greater than it is for water.
- (d) If a pipe line rises above the hydraulic gradient, vapour locks will inevitably occur.
- (e) It is dangerous to fill completely with petrol any container or pipe liable to considerable variation of temperature, unless some safety valve or plug is introduced.
- (f) Fill pipes to be taken from bottom of the tanks to prevent cascading. Suction pipes to be not less than 6 inches from bottom of tanks to avoid entry of water.
- (g) Joints in pipes should be as few as possible to minimize the incidence of leaks.
- (h) Screwed joints, flanged joints with specially treated joint-rings, and victaulic joints are divergently used.
- (i) Tanks upon erection will be separately tested by air pressure at not more than 5 lb. per square inch, or by merely filling with water. Under an air test, exploration of seams and joints with soap solution will readily indicate leaks. Piping will be tested at a pressure of 30 lb. per square inch, preferably by the hydraulic method. Before use tanks should be cleaned internally.
- (j) Galvanized pipe-work must not be used for leaded petrol.

- (k) Ground drainage should be provided to ensure against the accumulation of petrol by leakage, and against flow from tanks to aircraft standings or any other vulnerable point in case of fire or bomb damage. Petrol interceptors should be fitted in drainage systems adjacent to filling or off-loading points and tank areas.
- (l) In general, pumps will be driven by I.C. engines or electric motors. Fire risks are reduced by installing the engine and pump in separate chambers, with the driving shafts passing through a hole in a fire-wall which is packed with fire resisting material. No electric switches will be placed in the pump room, and ventilation must be good. All electric fittings should be flame-proof.
- (m) Leaks in tanks may be corrected by tightening the bolts or by caulking.
- (n) In the siting of filling points near an airfield, less consideration generally need be given to camouflage than in the case of M.T. petrol installations, around which heavy concentrations of transport will sometimes give valuable information to the enemy. But the possibilities of successful camouflage and concealment must always be fully explored for development as circumstances demand.
- (o) Fire risks must be constantly kept in mind in siting and disposition. It may be necessary to build bund walls, capable of containing the total capacity of the tanks served.
- (p) Normal speed of filling into road vehicles to be 100-150 gallons per minute; aircraft 30-40 gallons per minute per nozzle.

## CHAPTER 23

### CAMOUFLAGE AND DUMMY AIRFIELDS

#### SECTION 170.—GENERAL

1. Concealment and camouflage upon airfields are of comparatively little importance to the force with air supremacy, but there are few phases in war when their possibilities can be safely ignored, and never should they be forgotten. The difficulties of successful achievement have constantly increased with the improvement of air photography and refined stereoscopic methods of interpretation. Opportunities of deceiving or frustrating a raiding bomber dependent upon direct visual observation for spotting an important target will always remain. A sound knowledge of camouflage principles and practice is a fundamental part of the training of airfield engineers, in readiness for special demands upon their services, no less than in qualifying them to assist in the interpretation of air photographs covering enemy airfields and ancillary installations.

2. The fundamental success of airfield camouflage lies in the availability and selection of sites which favour natural concealment, presenting a variegated pattern, and which allow sufficient dispersal to make the introduction of artificial methods of disguise or concealment worth while. The skilful concealment of a German runway by assimilation with adjacent ground patterns is illustrated in the air photograph at Plate 89.

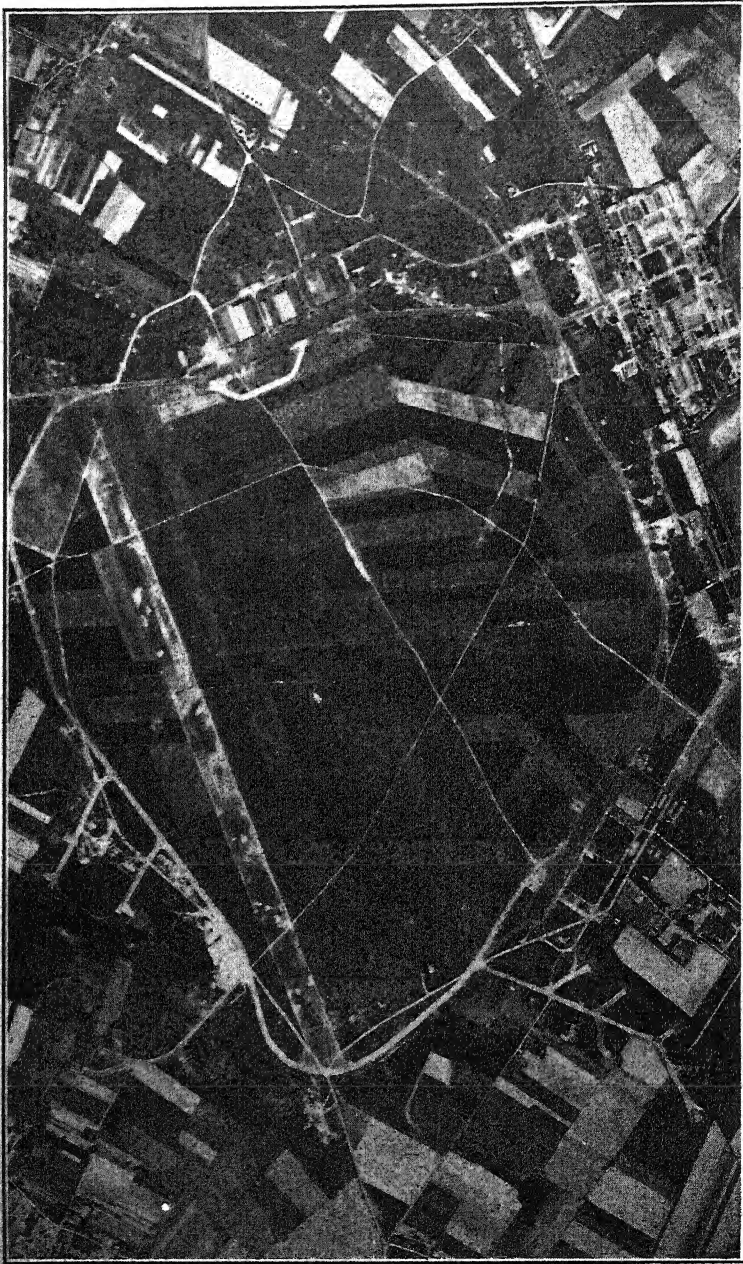


PLATE 89.—WELL CAMOUFLAGED GERMAN AIRFIELD WITH TWO PAVED RUNWAYS

## SECTION 171.—CAMOUFLAGE METHODS AND MATERIALS

1. The treatment of buildings follows established practice. Aircraft pens casting deep and regular shadows call for urgent attention amongst technical structures. Owing to the conspicuousness of tracks leading to pens and hangars, direct results are commonly inadequate to justify any diversion of effort from other services, except where trees and other growths provide a natural basis for confusion of picture.

2. The camouflaging of artificial runways, whether paved or of prefabricated type, presents a heavy task, and only in exceptional circumstances is the effort justified to any advanced degree. The two objectives are to reduce the contrast in colour and texture between the runway surface and surrounding terrain, and to remove the "shine" of a paved area due to water or smooth surfacing.

- (a) The conspicuousness of steel mats is reduced by the earliest possible cultivation of grass and weeds.
- (b) For other runways, especially where colouring is to be applied, paved surfaces must ordinarily have a texture coat applied during construction or by special treatment subsequently. The usual method is to give the surface an adhesive coat of bitumen or tar, "blinding" it with some non-reflecting substance such as  $\frac{1}{4}$ – $\frac{1}{2}$ -inch cinders, sawdust or small wood chippings.

To ensure adhesion of the seal and texturing material to concrete or old bituminous runways the surface should be cleaned by brooming and then primed, while dry, with a cut-back at 0.1 gallon per square yard. For sealing, bitumen should be applied hot at a suitable rate—up to 0.3 gallon per square yard for coarse texturing.

Texturing material should be applied immediately after the seal. Hammer-mill chips have been used successfully on airfields in Britain, and for this purpose a portable machine has been developed for cutting up local timber. The chips can be given any suitable colour. With spray painting, a gallon of paint will cover 24 square yards of wood chips.

Stone chippings, of various colours, are sometimes used, but are less satisfactory, being liable to work loose and become a source of damage to aircraft tyres and propellers.

3. Special camouflage paints and coloured bituminous emulsions have been widely used for reducing contrasts or for producing camouflage patterns.

A paint known as "camcolour" was developed for airfield work in the Middle East in a wide range of colours. The material is moderately successful in a dry climate. It is composed of slaked lime, coloured earths, and limestone filler, ground together to a paint fineness, with an addition of common salt. Yellow, red, black or green pigments are intermixed in percentages from 15 to 50 per cent.

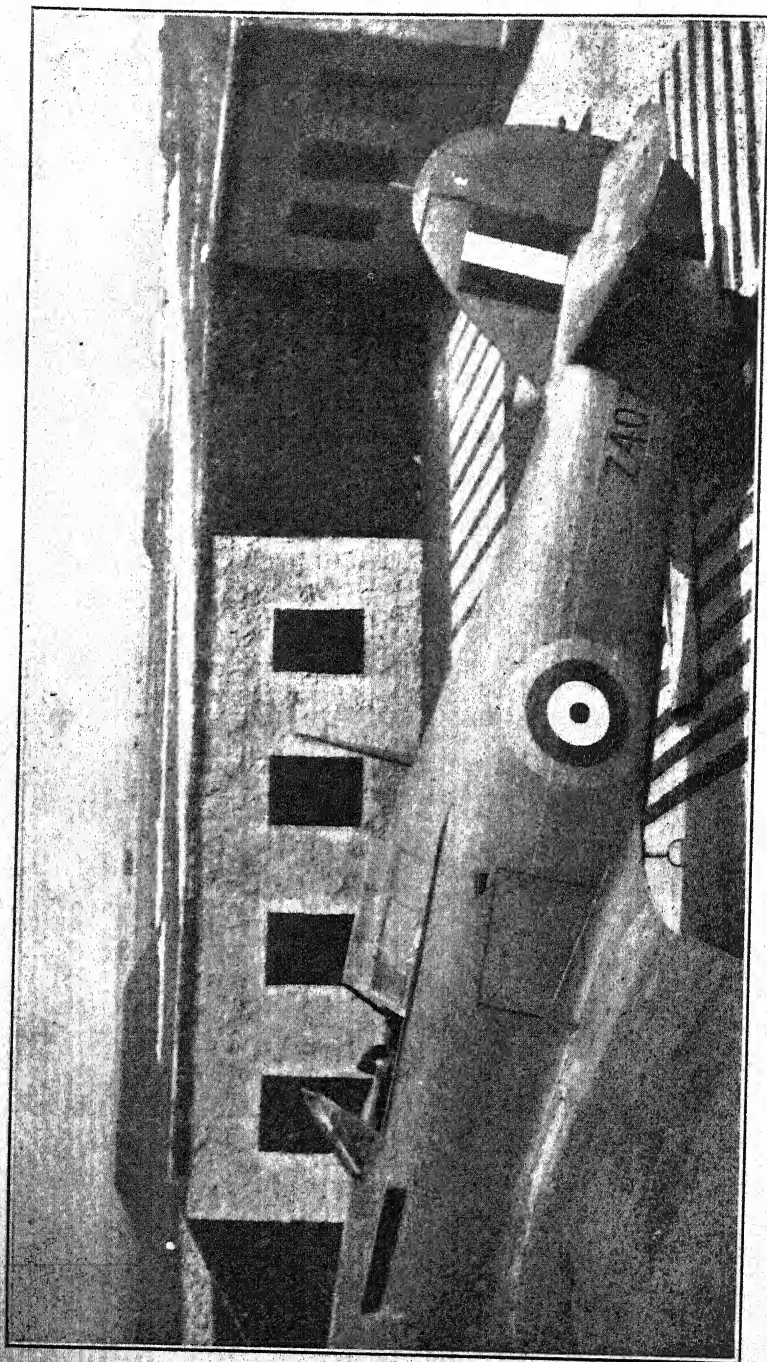


PLATE 91.—CAMOUFLAGED MASONRY PEN. PALESTINE.

## CHAPTER 24

## ASSISTED TAKE-OFF AND ARRESTER GEAR

## SECTION 173.—GENERAL

The provision of assisted take-off and arrester gear devices upon short landing grounds would constitute a major engineering problem unlikely to call for consideration without long planning and consultation between the services concerned. The adaptation of aircraft carrier principles to land requirements, either in amphibious operations or mountain warfare, when landing sites only of very restricted dimensions can be found, is a question which has, however, frequently been raised for discussion. The general principles should be understood.

## SECTION 174.—ENEMY METHODS

1. The enemy is reported to have employed methods of assisted take-off, but no reference to his use of arresters has appeared. The application has been to loaded bombers needing the extra acceleration to clear obstructions at the end of a comparatively short runway. Two systems have been employed—the winch and the rocket.

2. In the former case, the aircraft is pulled forward at great speed by means of a winch (in the line of take-off) equipped with about 300 yards of cable. The winch is cleared by the airborne aircraft, from which the rope becomes disengaged by its own weight. Controls include a small rear winch to hold the aircraft against the draw of the main rope while the engines are being run-up.

3. The surer method involves the fixing of two large pear-shaped rockets to the underside of each wing. By electric control the thrust can be made to last for 30 seconds, or can be prematurely cut out. After use, the rocket gear is detached and dropped by parachute at safety height.

## SECTION 175.—AIRCRAFT CARRIER METHODS

1. In the consideration of projects involving the use of carrier methods, it must be appreciated that only Fleet Air Arm or specially modified R.A.F. types of aircraft can be served. A substantial tonnage of special gear has to be imported and some heavy plant to be installed under conditions likely to be unfavourable.

2. Details of the catapult engine, arresting engine, compressor-generator unit, metal deck and accessories, representing modified carrier practice, need not be given. A complete assembly weighs 250 tons, the heaviest item being the catapult engine of about  $5\frac{1}{2}$  tons. Assuming good approaches, a landing strip of under 150 yards might be adequate for special aircraft.

3. Alternately, rocket-assisted take-off gear and drag-chain arresters would be available for aircraft fitted for such service. A wire rope crash-barrier might also be required, where over-run conditions prohibit the gradual deceleration of running aircraft.

## SECTION 176.—PRACTICAL CONSIDERATIONS

1. In practice the airfield construction engineer is more likely to be called upon to consider opportunities for aiding aircraft upon a restricted site by local improvisations. Suitable slopes may be found to speed the take-off run without risk of tipping up the aircraft before becoming partly airborne. For landing, a strip can be surfaced with steel tracks on a rising slope to provide safe braking effect. A crash barrier can be built to save aircraft from certain destruction where serious obstacles are irremovable.

2. The problem, in general, inevitably demands the consideration, for specific aircraft, of the length of ground required for take-off, as opposed to that required for landing. The question is complicated by the fact that on taking off with maximum load the whole of a runway will be used, whereas upon landing in poor visibility, or in trouble the touch-down will often be at a considerable distance from the end of the runway, even when markers are conspicuous. In cases where special help is needed because of the shortness of the site available, it follows almost inevitably that approaches are not highly favourable for touch-down precision. On the other hand, the take-off with full load is always the more risky operation, whilst the landing of the lighter aircraft on a short run can be robbed of much of its danger by heavy braking, by a sluggish runway surface, and a final crash-barrier or upward slope.

3. The conclusion commonly arrived at in varying circumstances is that taking-off demands the longer run, and that the introduction of assisted take-off gear does not mean that the installation of arresters with elaborate drag-chain facilities is also necessary.

## CHAPTER 25

## DESTRUCTION AND REPAIR OF AIRFIELDS

### SECTION 177.—GENERAL

1. Airfield engineers should have a sound knowledge of these activities. In the earlier phases of a war they may be called upon to consider or put into effect various schemes of demolition and obstruction calculated to deny landing facilities upon our own airfields if captured by the enemy. In the latter phases a thorough knowledge of principles and practice is essential for officers upon reconnaissance and for those responsible for planning the rehabilitation of evacuated enemy airfields.

2. In all cases the aim will be to make the task of repair or new construction as costly in time, men and material as possible; particularly in time, so that occupation by the incoming air force will be long delayed.

Extensive schemes of airfield demolition have rarely been applied. They may be justified by probable results when contributory difficulties are likely to arise from coincident heavy rainfall or from a high water table, making the restoration of a strong surface course an abnormally difficult task.

3. Upon hasty withdrawal there is little time between the departure of the defending air force and the approach of enemy ground troops for extensive demolitions. Those prepared are often indifferently executed.

Upon a deliberate retirement it is generally desirable to conceal intentions as late as possible. Obstructions and preparations upon runways which can be readily detected from air photographs are thus discouraged.

## SECTION 178.—DESTRUCTION AND OBSTRUCTION OF AIRFIELDS

1. The problem resolves itself into a skilful selection of methods calculated to produce the best results with minimum time and resources. The landing lane or runway is the most important factor for consideration in nearly all cases, and is commonly the most difficult of effective treatment. Drainage systems may prove a highly vulnerable feature, capable of being disorganized with comparatively small expenditure of men and materials at culverts and junctions.

Other points for consideration will be hangars, petrol dumps and installations, water and power plants, and any key points on taxi routes and access roads.

2. In runway demolition, the object will be to displace as much soil or other materials as possible at such points as to delay longest the construction of temporary strips and dispersals for emergency operations.

In the case of heavy concrete runways, however, especially if reinforced, every effort must be made to damage as big an area as possible rather than strive for removal of maximum tonnage of concrete and base.

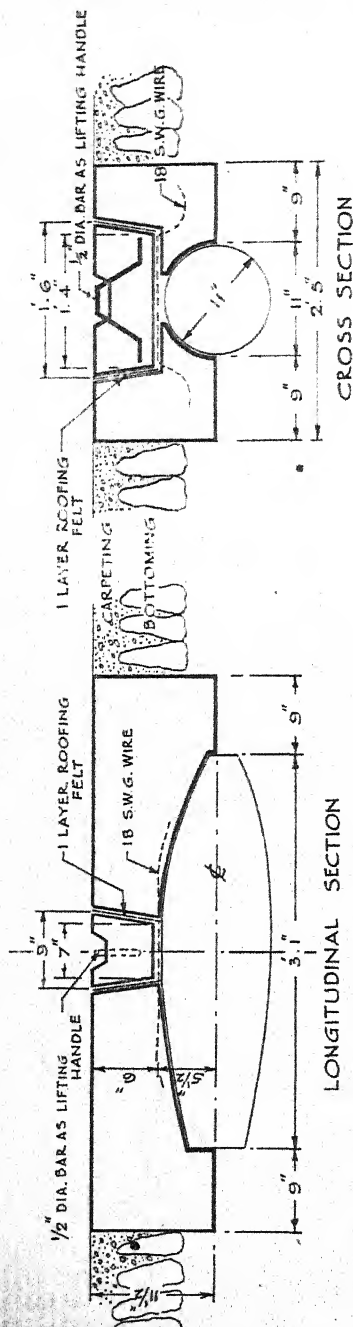
3. The demolition of concrete or macadam runways is greatly facilitated by the construction of mine chambers, with strong covers, before the airfield is ready for service. This practice was widely adopted in Middle East during 1941-42. In such schemes obsolete or captured aerial bombs have been frequently used, the size, depth and number of chambers being governed by bomb types available. (See Plate 92.)

However well constructed, these precharged mines are not favoured by an air force. Water may get in and weaken the surrounding soil. Covers need constant supervision. Approved schemes have involved the making of three chambers in each row across a 50-yard runway, with rows about 200 yards apart.

4. For hasty work the blowing of craters may be undertaken by means of pits, camouflet tubes, push-pipes, or other methods, in accordance with normal road demolition practice.

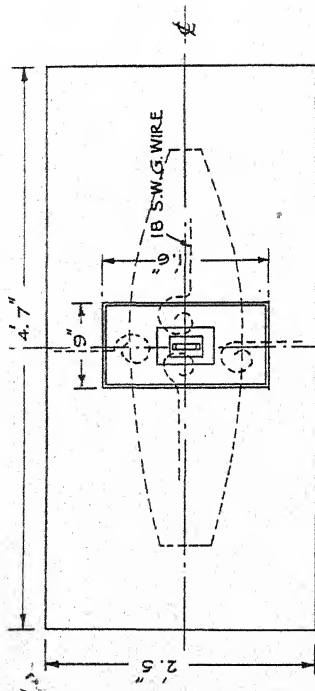
5. Prefabricated steel mats should be taken up and made unserviceable by fire or other means if they are performing an important function. Complete removal for service elsewhere is almost invariably impracticable in the circumstances.

6. On natural surfaces ploughing, combined with mines and booby traps, is commonly the most profitable method of obstruction. Heavy tractors with rooters can cause great damage on almost any type of airfield with remarkable rapidity. Such easily detected methods of obstruction are unlikely to be attempted unless capture is imminent, and it is not customary to risk heavy plant, urgently required for constructive purposes, upon speculative ventures so far forward during retirement.



## NOTE:

EXCAVATE FOR & PLACE OMB IN POSITION.  
 PLACE CONCRETE UP TO LEVEL OF TOP OF BOMB.  
 INSERT 4 NO TYPING WIRES TO BE 1.6" LONG - 6  
 INTO CONCRETE - THE REMAINING 12" TO BE  
 COILED & LAID ON TOP OF BOMB.  
 CAST REMAINDER OF CONCRETE AROUND  
 SHUTTERING FOR HOLES.  
 LINE HOLE WITH ROOFING FELT & CAST IN CONCR. PLUG.  
 AFTER SETTING REMOVE PLUG & FELT AND  
 RE-LAY PLUG IN OIL AND SAND.



PLAN  
 PLATE 92.—DEMOLITION CHAMBER

7. Fire, explosives, and equipment for superficial disturbance of soil should be relied upon as the basis for all projects. The demand for maximum simplicity defeats most other schemes, though possessing features of attractive ingenuity. For instance, the destruction of grass runways and shoulders by an adaptation of the mole plough has been proposed and tested. Speed and invisibility are favourable characteristics. The method involves drawing behind the plough a long rubber or Neoprin tube containing 12 oz. per foot run of 50 per cent. N.G. polar gelignite and cordtex. Lengths up to 50 feet would be practicable. Ploughed at a depth of 2-2½ feet, the detonation of the charge creates a trench or ruptured zone about 12 feet wide and 3-4 feet deep. Special provision is considerable and opportunities for application would be very rare.

8. The demolition of runways by means of push-pipes from each side is not as applicable to a 50-yard wide runway with wide flat shoulders—required to be clear for flying safety until evacuation—as to a road, along which work can proceed without traffic interference.

9. The obstruction of vital areas by means of derelict aircraft, transport and plant, combined with anti-personnel mines and booby-traps, has frequently been effected as a subsidiary measure of delay.

#### SECTION 179.—REPAIR OF AIRFIELDS

1. Ground and air reconnaissance show whether it would be better policy to construct new strips than to clear or repair those already in existence. This decision will be governed by the time, labour, plant and materials made available for the task.

2. The work will proceed as soon as strips and vital areas have been cleared of mines and booby traps. Filling of bomb craters, repairing and replacing damaged pavement on runways and taxiways will be the common tasks. Repair of damaged drains is important. Wherever possible mechanical equipment should be used to fill craters. Stock piles of hardcore and gravel are usually dispersed in readiness around the airfield in anticipation of enemy bombing.

3. Craters may be filled by standard methods :—

- (a) Remove all water by pumping.
- (b) Remove all debris and disturbed soil.
- (c) Fill with granular material such as clinker, hardcore, or gravel in layers not greater than 1 foot, thoroughly tamping each layer.
- (d) Apply new surface material as required.

Repaired craters must be inspected periodically for settlement, especially after the first heavy rain.

Facilities for repair are normally assembled at a centre airfield for the service of a group.

4. Landing and taxi-ing surfaces must be examined for metal fragments from bombs, and "crows feet" before aircraft operate. Remove by hand picking or brushing.

## CHAPTER 26.

## MAINTENANCE OF AIRFIELDS

## SECTION 180.—GENERAL

1. Hastily constructed airfields require obviously more frequent and careful maintenance than permanent types of aerodrome. A small party of engineers and pioneers will be necessary to carry out repairs to drains, runways, prefabricated mats, etc., and for the maintenance of markers, beacons, lines and stock piles, and for dust alleviation, etc. Clearance of snow or weeds is also a demand upon occasion.

2. Inspection and maintenance will need to be especially thorough after heavy rains and thaws. Each defect must be examined with a view to the determination and removal of the cause, if possible.

## SECTION 181.—DRAINAGE

All accumulations of debris, weeds, and silt must be removed from drains. Erosion damage to ditches must be corrected. Clean-outs and junction boxes require periodic cleaning. Defects in the drainage system must be corrected promptly. Results of over-run by aircraft need close attention.

## SECTION 182.—RUNWAYS OR PAVEMENTS

1. Soft and yielding spots must be corrected. Where this is due to a weak sub-grade, the defective soil is removed and replaced by selected granular material well compacted. In the case of seepage, methods of drainage or water-proofing may have to be improved.

## 2. Surface courses

- (a) Untreated and unprimed stabilized soil surfaces require continuous maintenance, such as light scarifying or blading, followed by sprinkling and rolling. Surface ravelling and ruts may be patched with stabilized soil mixture.
- (b) Bituminous surfaces require frequent treatment, especially at the ends of runways and on taxi-tracks and turning points. Surface abrasion and wear may be corrected by bituminous retreatment.
- (c) Joints and cracks in concrete slabs are repaired with a hot asphalt or tar seal. On permanent airfields complete maintenance of joints should be carried out once in the spring and again in the early autumn. Depressed and broken slabs, due to ordinary foundation settlement, may be resurfaced with bituminous premix to bring the runway surface up to grade. Broken slabs due to major foundation defects are replaced after foundation renewal.

3. Wire tracks.—Individual sections are easily replaced when damaged.

- (a) Sommerfeld track calls for constant maintenance, attention being paid to soil condition and drainage. Broken wire ends must be remedied immediately, otherwise serious damage will be done to aircraft. Major contortion of track by heavy loading and soft sub-soil is very difficult to put right.
- (b) Square mesh tracks may require constant additional fastening down with screw pickets, otherwise billowing is likely to occur in the surface.

- (c) Small local subsidences due to unequal earth compaction, and pot-holes due to rain, sometimes occur under P.S.P. The track should be jacked up to the required level and the ground beneath packed up with gravel, clinker or other material shovelled through the holes in the plank. When it is necessary to take up the mat in order to lay a new base course or place an underlay of coir matting, the quickest method is to roll back the P.S.P. Complete removal is a more effective method, but the planking will generally be much more difficult to relay.

### SECTION 183.—TURF AIRFIELDS

Regular mowing is essential to preserve a dense turf with a matted root system. The grass should be kept down to a height of 3-4 inches during the growing season. At the end of autumn grass should be left 2-3 inches long. Avoid close mowing during long spells of dry weather. Rolling is carried out to compact loose soil around the roots. Normally, the action of aircraft does all the rolling, and more, than is necessary. To increase turf aeration and porosity over large areas, special equipment may be used; an ordinary digging fork will suffice over small patches. Fertilizers should only be applied under expert guidance. Lime may improve the mechanical as well as the chemical condition of the soil. If a lime requirement exists, ground limestone may be applied up to two tons per acre, at almost any time, except to very new grasses.

### SECTION 184.—SNOW AND ICE CLEARANCE

1. This is normally the responsibility of the Air Force unit concerned. Engineers may be required to render assistance with mechanical equipment. Snow may either be compacted by rolling and dragging, or preferably cleared away by snow ploughs. Where snow is compacted, maintenance will aim to reduce the thickness so that when the thaw comes there will be no more than 3 inches on the runway.

2. Ice coatings on runways and taxi-tracks are treated with a sprinkling of sand. Accumulated sand on paved runways and taxi-tracks is removed by power brooming in the spring. The use of salt (sodium chloride and calcium chloride) for ice control on airfields is effective but not generally recommended, owing to its deleterious effect on engine parts.

### SECTION 185.—WEED KILLING ON AIRFIELDS

This will be best carried out before the construction of paved runways. Weeds grow through the cracks, which they tend to widen, and are very difficult to exterminate. The selection of the right type of weed-killer, suitable for different plants, climates and soils, can only be decided by experiment.

Known weed-killers are :—

- (a) Sodium arsenite compounds—10 per cent. solution. About 1 ton per 100,000 square yards.
- (b) Sulphuric acid—2 per cent. solution. 200 Kg for 100,000 square yards.
- (c) Common salt—subject to experiment. Trials in the Middle East suggested that three dressings were necessary.

## CHAPTER 27

## RUNWAY LIGHTING AND NIGHT FLYING AIDS

## SECTION 186.—GENERAL

1. Engineer officers have rarely been called upon to accept responsibility for the lighting of airfields, in operational areas. They must, however, be prepared to assist with the work and should be acquainted with general principles. The provision of "night flying aids" is related to conditions of flying approach, with direct bearing upon engineer reconnaissance and report in the siting of new airfields in difficult country.

2. Reference will be made to common practice in a distant theatre of war, where heavy installations are rarely demanded or practicable.

## SECTION 187.—RUNWAY LIGHTING

1. Three systems of runway lighting are in vogue :—

- (a) Permanent electric flarepaths.
- (b) Portable electric flarepaths.
- (c) Non-electric and "Glim" lamps.

The standard length for flarepaths is usually 1,600 yards.

2. For the installation of lights on a permanent station, the most exacting stores item is cable—T.R.S. cable being preferred to lead-covered. For funnel, obstruction, flarepath, taxi-ing lights, and glide path indication, the demand on an average station may approximate 40,000 yards run of 0.0225 square inch section cable, 12,000 yards of 0.01 square inch, and 10,000 yards of 0.0007 square inch. If an outer circle of lights is provided a further 22,000 yards of .0225 square inch section cable is required.

3. Individual lamp equipment, inferior because of labour involved and ready location by intruders, comprises a variety of types, as follows :—

- (a) *Glim lamps*.—Portable flarepath lights fitted with electric lamps, operated by a 2-volt 20-hour accumulator. These lights are not visible at a greater height than 1,000 feet in the vicinity of the airfield. The lamp bulb and reflector are so mounted that on uneven ground the mirror remains horizontal. A flarepath which is not wired up in the normal way and connected to a switchboard in the control tower is referred to as "non-electric". Glim lamps are sometimes adapted by removing the normal lamp and mirror, installing an ordinary electric bulb and fitting a plain glass dome on top. They are then wired up as a portable electric flarepath.
- (b) *Gooseneck flares*.—These flares give a strong light, apt to be reduced in a high wind. They have an endurance of 14 hours. It is usual to slip over the wick and spout, a rocket tube or a cylindrical metal can, for rapidly extinguishing these lights.
- (c) *"Money" flares*.—This type of flare is very crude, consisting of a bucket of paraffin in which is placed a dome-shaped piece of asbestos held in a wire form which has a handle on the top. The bucket is fitted with a detachable lid. For lighting, the lid is removed and a flame is applied to the asbestos dome. The resulting light is stronger than that from a "gooseneck." These flares are used in conditions of bad visibility. They are often improvised by using a loose piece of asbestos and an ordinary bucket. The bucket lid is used for rapidly extinguishing the flare.

## SECTION 188.—NIGHT FLYING LIGHTS

Night flying lights other than those on the aircraft comprise :—

## 1. Aids to navigation :—

(a) *Aerial lighthouses*.—These are known as "occults". They are white beacons which give a flashing light with a one-letter characteristic. Essentially for navigation purposes, the co-ordinates of their positions are in the possession of the pilot.

(b) *Landmark beacons*.—These are red beacons, placed in the vicinity of airfields, which emit a flashing light with a two-letter characteristic, and are known as "pundits". They are self contained and no engineer or works services are necessary.

2. **Night landing lights**.—All the normal lighting aids placed on the airfield to help the pilot to land safely come under this head.

(a) *Obstruction lights* are red and are used for marking obstructions to aircraft in flight or on the ground. In certain circumstances they may be hooded. They are not used for marking runway boundaries.

(b) *Flarepath*.—Commonly single row of lights for non-electric types and double for electric installations. The double flarepath is the standard for permanent electric flarepaths, enabling the pilot to get a perspective of the runway. With a single path, the landing and take-off is made with the flares on the port-side of the aircraft. For a typical layout of a portable electric flarepath (*see* Plate 93).

(c) *Totem poles*.—These form an indispensable part of airfield lighting. They consist of six lights in the vertical plane placed close together, mounted on poles. They are used to indicate the extent of the landing area, and may be battery or mains operated. Usually positioned 50 yards from the edge of the runway.

3. **Floodlights**.—The mobile floodlight is ordinarily 100 yards from the end of the runway and 25 yards to the left when facing into the wind. The light is focused to illuminate the best point of touchdown.

4. **Angle of approach indicators**.—These enable the pilot to control his angle of glide when coming in to land. They should be placed 75 yards upwind from the end of the runway, 6 yards outside the edge of the runway, and slightly toed in. If two are used the left-hand one is set at  $4\frac{1}{2}$  degrees above horizontal, and the right at  $5\frac{1}{2}$  degrees. If only one is used it should be set at  $4\frac{1}{2}$  degrees.

5. **Ground control lights**.—For taxi-tracks and marshalling points, blue and amber lights are used, blue nearest the centre of the airfield, amber on the outside edge of the airfield. Single lights are used to mark taxi-tracks, and equilateral triangles of lights, set vertically on posts 3 feet high, not nearer than 10 yards from the edge of taxi-tracks for marshalling areas. Guiding vehicles, when used to lead aircraft from the runways to dispersal areas, are equipped with "STOP" and "GO" lights of low power.

6. **Funnel lights**.—Ordinarily associated with any semi-permanent form of flarepath. Standard type consists of two lights at 500 yards, four lights at 1,000 yards, and six lights at 1,500 yards from the downwind end of runway. In practice a single pair of funnel lights 300 yards apart is normally used 1,200 yards downwind of flarepath. The lights are 60-watt battery operated.

As all established lighting systems soon become known to the enemy, special changes will be made to meet any demands for secrecy or deception dictated by the tactical situation.

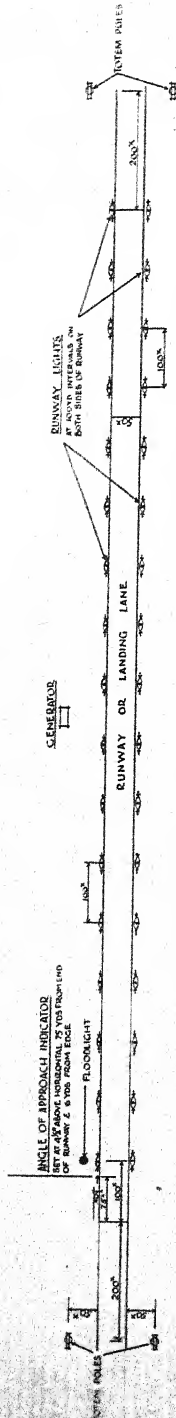


PLATE 93.—TYPICAL LAYOUT OF PORTABLE ELECTRIC FLAREPATH

## APPENDIX I

## ORGANIZATION AND DETAILS OF AIRFIELD UNITS

The channels through which the air forces receive engineer guidance and transmit their demands for engineer services are decided by the senior engineer officer in the area of operations concerned, in consultation with Air Force headquarters. Organization, bringing differently constituted units of Royal Engineers, of R.A.F. Airfield Construction Service and U.S. Aviation Engineers into effective relationship, is necessarily elastic. With airfield units, trained and equipped for all tasks, the chain of command can be modified speedily to meet changing circumstances.

Technical control is exercised by the senior engineers of British Army formations or of U.S. Army Air Forces, except in the case of R.A.F. Airfield Construction Units, when control may be exercised either by the senior R.A.F. Airfield Construction Officer, or by the senior engineers of British Army formations as circumstances dictate.

Chief engineers function through deputies or senior air staff officers, who act as technical advisers and exercise such executive control as the situation may demand.

Details of units organized and equipped for airfield and ancillary engineer services are summarized below :—

*N.B.—The details given in paras. 1-4 below are correct at the time of going to press, and it is not proposed to publish continual amendments to this volume to keep them precisely up to date. They should serve as a useful guide until major changes occur.*

## 1. Airfield Construction Group, R.E.

(a) The establishment of an Airfield Construction Group consists of :—

C.R.E. ((Lieut.-Colonel) ... ..	1
Field Engineers ... ..	3
(Major, Captain and Subaltern, R.E.)	
Adjutant (Captain, R.E.) ... ..	1
Major (Pioneer Corps) ... ..	1
Medical Officer, R.A.M.C. ... ..	1
Quartermaster (Pioneer Corps) ... ..	1
Total officers ... ..	8

Total other ranks with attached personnel... .. 49

Trades include 10 driver-operators and one driver-mechanic.

C.R.E. Airfield Construction Group will normally have under his command :—

Road Construction Companies, R.E. ... ..	2
Pioneer Corps Companies ... ..	2
L.A.D.—Type B ... ..	1
Bomb Disposal Section or Party ... ..	1

Total strength : 36 officers and 1,041 other ranks.

## Transport:—

Cars—4-seater	...	...	...	...	...	1
5-cwt.	...	...	...	...	...	2
Trucks, 15-cwt. G.S.	...	...	...	...	...	2
Trucks, 15-cwt., Office	...	...	...	...	...	1
Trucks, 15-cwt., Wireless	...	...	...	...	...	5
Lorries, 3-ton	...	...	...	...	...	5
Trailers, water	...	...	...	...	...	3
Trailers, 1-ton, G.S.	...	...	...	...	...	2
Motor cycles	...	...	...	...	...	5

## (b) Road Construction Company

Total strength—8 officers, 206 other ranks  
H.Q., 2 officers (major and subaltern) and 38 other ranks,  
including attached personnel.

Two platoons, each 2 officers (captain and subaltern) and 43  
other ranks.

Plant platoon, 2 officers (captain and subaltern) and 82 other  
ranks.

## Rank and file include:—

Operators, excavator	...	...	...	...	...	36
Drivers, road roller	...	...	...	...	...	6
Engine fitters	...	...	...	...	...	9
Engine hands, I.C.	...	...	...	...	...	10
Driver-mechanics	...	...	...	...	...	5
Drivers of vehicles	...	...	...	...	...	66
Blacksmiths, bricklayers, carpenters, concretors, masons, painters, plumbers and pipe-fitters, quarry- men, sheet-metal workers and welders	...	...	...	...	...	23

## Transport:—

Cars, 4-seater	...	...	...	1	Lorries, 3-ton, machinery,	
Cars, 5-cwt	...	...	...	3	R.E. "X" ...	1
Trucks, 15-cwt. G.S....	...	...	...	5	Trailers, 15-cwt., water	2
Trucks, 15-cwt., office	...	...	...	1	Trailers, 18-ton, Carriemore	10
Trucks, 15-cwt., water	...	...	...	1	Motor cycles	6
Tractors, medium	...	...	...	10	Trailer, 10-cwt., 2-wheeled, machinery type P (welding)	1
Lorries, 3-ton, G.S.	...	...	...	3	Trailer, 2-wheeled, mobile	
Lorries, 3-ton, tipping	...	...	...	12	servicing	1

## Mechanical Equipment:—

Tractors, crawler, Class IV, angledozer and P.C.U.	...	...	...	2	Shovels and skimmers, each	2
Tractors, crawler, Class II, angledozer and P.C.U.	...	...	...	6	Ditchers, plough type	2
Scrapers, 8-yd.	...	...	...	4	Rooters, light	2
Graders, motor	...	...	...	2	Mole plough	2
Graders, towed	...	...	...	2	Road sprays, 250-gal. bitu- men	2
Rollers, 6-ton	...	...	...	3	Road sprays, 60-gal., cold emulsion	2
Rollers, sheepsfoot	...	...	...	3	Concrete mixer, 10/7	1
Excavators, 10 RB- $\frac{3}{4}$ cu. yd.	...	...	...	4	Carts, watering, 300-gal., draw bar	1
Dragline jib, ropes and crane hooks	...	...	...	4	Compressors, trailer, 105 cu. ft.	2
Dragline buckets	...	...	...	4	Dumpers, 2-yd.	8
Trencher attachment	...	...	...	2		

## 2. U.S. Aviation Engineers

### (a) Aviation Engineer Battalion :—

Total strength : 33 officers, 774 enlisted men.

Lieut-colonel	...	...	...	...	...	1
Major	...	...	...	...	...	2
Captains (including medical)	...	...	...	...	...	9
Lieutenants	...	...	...	...	...	21

The battalion is organized in H.Q. and H.Q. company, with three lettered companies and a medical section. This is the usual field operating unit. Each company comprises H.Q. and three platoons, of strength 5 officers and 178 enlisted men.

#### Transport :—

Car, 5-seater	...	...	...	1	Truck, 2½-ton, tippers, winch	37
Truck, ¾-ton—recee. and weapons	...	...	...	8	Truck, 4-ton, tippers, winch...	14
Truck, ¼-ton	...	...	...	16	Truck, 6-ton, with winch	3
Truck, 1½-ton—radio and stores	...	...	...	2	Truck, fuel tank	1
Truck, 2½-ton—stores	...	...	...	8	Trailers, 8 and 15-ton	8

#### Mechanical Equipment includes :—

Rollers, sheepsfoot, two drum in line	...	...	...	3	Rooter, medium	...	...	1
Rollers, rubber-tyred	...	...	...	2	Crane, towed, 30-ft.	...	...	1
Rollers, ¾-ton, tandem	...	...	...	2	Rotary tiller	...	...	2
Rollers, 10-ton, 3-wheel	...	...	...	1	Trencher, vertical boom	...	...	1
Motor graders	...	...	...	8	Concrete mixer	...	...	2
Towed grader	...	...	...	2	Asphalt distributor	...	...	1
¾ cu.yd. shovel, tractor-mounted	...	...	...	2	Asphalt heater...	...	...	1
Tractors with angledozers	...	...	...	11	Air compressors	...	...	4
Tractors, rubber-tyred	...	...	...	2	E.L. units, 3 and 5, K.V.A....	...	...	4
Scrapers, 8-cu.yd.	...	...	...	7	Asphalt repair equipment	...	...	1
					Water supply equipment	...	...	1

Plant required for a big task is drawn from regimental H.Q. and service companies, which act as pools and depots for additional equipment and specialized personnel.

### (b) Airborne aviation battalion :—

These units are organized, with light equipment, to perform the pioneer work of construction or repair of advanced airfields which are not accessible by overland movement of standard equipment. Units are specially trained to provide minimum A.L.G. facilities, and normally accompany an airborne or amphibious force.

Total strength :—28 officers, 1 W.O. and 501 enlisted men.

The battalion is divided into battalion H.Q., H.Q. and service company and three operating companies.

Equipment includes tractors, with dozers; trailers, rubber tyred; towed graders; scrapers; rollers; shovel loaders; trailers; soil mixers; asphalt kettles; air compressors.

All plant is of "development type," size and weight being limited by the capacity of transport aircraft or gliders available.

## 3. R.A.F. airfield construction service.

### (a) The R.A.F. airfield construction service consists of the following components :—

#### (i) Airfield construction wing (field force basis)—for light airfield construction in forward areas.

- (ii) Airfield construction wing (overseas basis)—for heavy airfield construction in L. of C. and base areas.
- (iii) Quarrying flights.
- (iv) Well boring flights.
- (v) Mechanical and electrical construction flights—to undertake mechanical and electrical work in connection with new airfields.
- (vi) Mechanical and electrical flights—for maintenance of mechanical and electrical services on airfields.
- (vii) R.A.F. plant depot.

(b) *Airfield construction wing (field force basis).*—A wing consists of 2 airfield construction squadrons, each consisting of 6 airfield construction flights, 1 field plant flight and 1 M.T. section. Total complement 44 officers and 1,252 O.Rs. The component units of the wing are :—

(i) *Wing headquarters.*—12 officers and 36 O.Rs. for administration and technical control of squadrons.

(ii) *Airfield construction squadron headquarters.*—12 officers and 69 O.Rs. Officers include :—

Adjutant	...	...	1	Equipment	...	1
Civil engineers	...	...	9	Medical	...	1

(iii) 6 *airfield construction flights.*—Each 58 O.Rs. including 11 foremen, carpenters, bricklayers, plumbers, concretors and drainlayers.

(iv) *Field plant flight.*—This field unit comprises 3 officers and 112 O.Rs., including :—

Plant engineers (officers)	2	M.T. officer	...	1
Plant operators	...	46	Fitters and	...
Drivers (M.T.)	...	29	mechanics	...
Other tradesmen	...	6		

The plant held includes :—

Dumpers, 2 cu. yd.	...	...	6	Mixers, rotary pulverizers,	
Power-graders	...	...	2	petrol-operated	...
Excavators, $\frac{1}{2}$ cu. yd., lorry-mounted with face shovel, dragline and crane attachments	...	...	1	Ploughs, trenching	...
Excavators, $\frac{3}{8}$ cu. yd., with face shovel, drag shovel, dragline, and skimmer attachments	...	...	2	Rollers, 8-10-ton	...
Tractors, crawler, Class II, with angledozer, P.C.U. or winch	...	...	1	Rollers, 2 $\frac{1}{2}$ -ton...	...
Tractors, crawler, Class III, with angledozer, P.C.U. or winch	...	...	4	Rollers, 5-6-ton	...
Tractors, crawler, Class IV, with angledozer, P.C.U. or winch	...	...	5	Rollers, sheepsfoot, 2 drum	...
Scrapers, 3 $\frac{1}{2}$ cu. yd.	...	...	2	Rollers, pneumatic tyred	...
Scrapers, 6 cu. yd.	...	...	2	Pumps	...
Scrapers, 9 cu. yd.	...	...	1	Mixers, concrete, 10/7	...
				Compressors, air, 105 c.f.m.	...
				Rooters, H.3	...
				Ploughs, agricultural	...
				Harrows, disc	...
				Harrows, spike-tooth	...
				Rollers, agricultural	...
				Mole-drainers	...
				Cutters, grass	...
				Saws, chain, portable, petrol-operated	...
				Sprayers, bitumen/water, pressure, 1,250-gal.	...
				Magnets, mobile, for D.4 tractor, Class IV	...

- (v) *M.T. section.*—1 officer and 79 O.Rs. including drivers M.T., fitters, mechanics and other tradesmen and administrative personnel.

Transport held by each squadron includes :—

Cycles, motor ... ..	16	Tractors, 20/25-ton, with	
Cranes, salvage, heavy ... ..	1	trailer ... ..	10
Tenders, 3-ton ... ..	30	Tenders, welding ... ..	1
Tenders, road sweeping ... ..	1	Tenders, power, 7 KW. ... ..	1
Tenders, tipping ... ..	39	Tenders, workshop ... ..	1
Tenders, water, 350-gal. ... ..	4	Vans, 15-cwt. ... ..	2
Tenders, petrol, 1,000-gal. ... ..	2	Trailers, flat, 8-wheeled ... ..	3

- (c) *Airfield construction wing (overseas basis).*—The wing consists of 3 airfield construction squadrons, and 1 plant squadron. Total personnel 58 officers and 2,368 O.Rs. The components of the wing are :—

- (i) *Wing headquarters.*—16 officers and 62 O.Rs. for administrative and technical control of the squadrons. Officers include :—

Administrative ... ..	7	Surveyor ... ..	1
Accountant ... ..	1	R.A.F. regiment ... ..	1
Civil engineers ... ..	4	Medical ... ..	2

- (ii) *Airfield construction squadron.*—10 officers and 563 O.Rs. and consisting of :—

*Headquarters.*—10 officers and 53 O.Rs., the officers including administrative 2, civil engineers 8.

*7 airfield construction flights.*—Each flight 58 O.Rs. including 11 foremen, carpenters, bricklayers, plumbers, concretors and drainlayers.

*2 artisan flights.*—52 O.Rs. including 31 foremen, carpenters, bricklayers, concretors, drainlayers, electricians, steel erectors, plumbers, and blacksmiths.

- (iii) *Plant squadron.*—12 officers and 617 O.Rs. consisting of :—

*Headquarters.*—6 officers and 59 O.Rs. Officers include administrative 2, plant engineers 3 and medical 1.

*Plant flight.*—2 officers and 208 O.Rs. including plant operators 141, fitters and mechanics 12.

*Workshops flight.*—2 officers and 75 O.Rs. including fitters, mechanics, electricians, blacksmiths and welders, carpenters and administrative personnel.

*M.T. flight.*—2 officers and 275 O.Rs. including drivers, M.T. fitters, mechanics, electricians, and administrative personnel

The plant held by the plant squadron includes :—

Dumpers, 2-cu. yd. ... ..	25	Drills, wagon-mounted, with accessories ... ..	1
Power-graders ... ..	5	Rooters, K.30 ... ..	2
Graders, blade ... ..	2	Power winches, Class I ... ..	2
Excavators, $\frac{3}{4}$ -cu. yd. with face shovel, drag shovel, dragline or skimmer scoop attachments ... ..	2	Power winches, Class IV ... ..	2
Excavators, $\frac{3}{4}$ -cu. yd., with face shovel, drag shovels, dragline, skimmer scoop, crane or grab attachments... ..	6	Scrapers, 3 $\frac{1}{2}$ -cu. yd. ... ..	2
Tractors, crawler, Class I, with angledozer and P.C.U. ... ..	14	Scrapers, 6-cu. yd. ... ..	3
Tractors, crawler, Class II, with angledozer and P.C.U. ... ..	2	Scrapers, 9-cu. yd. ... ..	2
Tractors, crawler, Class III, with angledozer and P.C.U. ... ..	3	Scrapers, 12-cu. yd. ... ..	3
Tractors, crawler, Class IV, with angledozer and P.C.U. ... ..	6	Scrapers, motorized, 12-cu. yd. ... ..	2
Derricks, 50-ft. ... ..	1	Hi-lift shovels, $\frac{3}{4}$ -cu. yd. ... ..	3
Sprayers, bitumen/tar ... ..	3	Ploughs, trenching ... ..	1
Drying and mixing units, 10 cu. ft. ... ..	5	Ditchers ... ..	2
Mixers, bitumen/tar, 10-cu. ft. ... ..	5	Rollers, 2 $\frac{1}{2}$ -ton... ..	4
Boilers, tar, 320-gal. ... ..	20	Rollers, 8 to 10-ton ... ..	8
Boilers, tar, 50-gal. ... ..	3	Rollers, sheepsfoot, 2-drum ... ..	6
Crushing and screening plant—		Rollers, pneumatic-tyred ... ..	6
25 cu. yd./hr. ... ..	1	Power rammers ... ..	3
10 tons per hour ... ..	1	Pumps ... ..	24
Granulators, 16 ins. $\times$ 9 ins. ... ..		Ploughs, agricultural ... ..	2
Conveyors, belt, portable ... ..	4	Harrows, disc ... ..	1
Compressors, air, with accessories ... ..	7	Harrows, spike-tooth ... ..	1
		Drills, seed ... ..	1
		Mole drainers ... ..	1
		Cutters, grass ... ..	1
		Generators, 18–22.5 KW. ... ..	3
		Snow-ploughs ... ..	6
		Sprayers, bitumen/water pressure 1,250-gal. ... ..	4
		Mixers/rotary pulverizers ... ..	2
		Cranes, tractor operated, 40,000 lb. capacity ... ..	1
		Cranes, tractor operated, 20,000 lb. capacity ... ..	1

All transport required by the wing is held by the plant squadron and includes :—

Jeeps ... ..	21	Tenders, petrol, 1,000-gal. ... ..	8
Cars, passenger, utility ... ..	11	Tenders, water, 350-gal. ... ..	6
Cranes, salvage, heavy ... ..	1	Tenders, welder ... ..	1
Cycles, motor ... ..	23	Tenders, workshop ... ..	1
Tenders, 3-ton ... ..	17	Tractors, 20/25-ton, with heavy trailer ... ..	10
Tenders, 30-cwt. ... ..	2	Vans, 15-cwt. ... ..	10
Tenders, road sweeping ... ..	1	Trailers, flat, 8-wheeled ... ..	4
Tenders, tipping ... ..	165		

- (d) *Quarrying flight*.—Normally attached to airfield construction wings. Total personnel of 2 officers and 172 O.Rs. which includes quarrymen, plant operators, fitters, mechanics, drivers M.T. and other tradesmen and administrative personnel. The following plant is held by the unit :—

Excavators, $\frac{1}{4}$ -cu.yd., with face shovel, dragline, skimmer scoop and grab attachments ... .. 2	Shot-firing equipment ... 4
Tractors, crawler, Class I, with angledozer and P.C.U. ... 1	Granulators ... .. 2
Tractors, crawler, Class IV, with angledozer and P.C.U. 2	Portable belt conveyors ... 4
Crushing plant, 25 tons per hour ... .. 2	Air hoists ... .. 2
Crushing plant, 10 tons per hour ... .. 1	Air compressors, with accessories ... .. 4
Wagon-drills with accessories 2	Rooters, K.30 ... .. 1
	Tipping wagons, double-sided 2 cu. yd. ... .. 32
	Light railway track with accessories ... 1 mile
	Diesel locomotives, 33/40 h.p. 2
	Blast hole drill with accessories 2

Transport held by a quarrying flight is :—

Jeeps ... .. 1	Tenders, petrol, 1,000-gal. ... 1
Tenders, 3-ton ... .. 3	Tractors, 20/25-ton, with heavy trailers ... .. 4
Tenders, water, 350-gal. ... 1	Tender, power, 7 K.W. ... 1
Tenders, tipping ... .. 8	

- (e) *Well boring flights*.—Well boring flights, attached to airfield construction wings, have a complement of 1 officer and 32 O.Rs. which includes drillers, blacksmiths and welders, fitters and mechanics and administrative personnel.

Plant held by the unit :—

Pumps, well ... .. 4	Pump barrels, 36 ins. $\times$ 5 $\frac{1}{4}$ ins. or 3 $\frac{1}{4}$ ins. ... .. 8
Boring rigs ... .. 2	Well casing, 6 ins., 8 ins., 10 ins. and 12 ins. ... 6,500 ft.
Boring tools and equipment 2 sets	Well casing couplings, 6 ins., 8 ins. and 10 ins. ... 600 ft.
Pumpheads ... .. 4	
Rising main, 4 $\frac{1}{2}$ ins. and 6 ins. dia. ... .. 1,600 ft.	

Unit transport consists of :—

Jeeps ... .. 1	Tender, welder ... .. 1
Tenders, 3-ton ... .. 2	Tender, water, 350-gal. ... 1
Tractors, 10-ton, with trailers 2	Van, 15-cwt. ... .. 1

- (f) *Mechanical and electrical construction flights*.—Mechanical and electrical construction flight, normally attached to an airfield construction wing, comprises 2 officers and 40 O.Rs. including electricians and specialist fitters, drivers M.T. and other tradesmen and administrative personnel.

- (g) *Mechanical and electrical flights*.—Mechanical and electrical flights normally have a strength of 55 O.Rs. and consist of specialist tradesmen, i.e., electricians, fitters stationary engine, mechanics stationary engine and administrative personnel.

- (h) *R.A.F. plant depot.*—The R.A.F. plant depot is the main holding and issuing depot for all plant and special technical equipment held by units of the airfield construction service. In addition to this function it also holds a range of heavy plant, which can be issued for particular operational purposes.

Plant includes :—

Concrete pavers (34 cu.ft. capacity).	Bucket loaders (3 cu. yd./min.).
Concrete spreaders, 20 ft. wide.	Mixing plant, macadam/soil, aggregate (25 or 40 tons per hour).
Concrete finishers, 20 ft. wide.	Batching plants.
Macadam finishers and spreaders (100 tons per hour).	Light railway equipment.

4. **Royal Marine engineer units.**—Royal Marine engineer units include M.N.A.F. (mobile naval air field) companies.

Strength of company—10 officers and 375 O.Rs., divided :—

	Officers		Other Ranks	
Administrative ... ..	...	2	...	58
Technical				
H.Q. ... ..	...	2	...	18
2 Platoons (Constructional) each	...	1	...	56
2 Platoons (Artisan) each	...	4	...	56
1 Mechanical Section ... ..	...	2	...	75

The mechanical section is divided into (1) plant, (2) transport and (3) workshop sub-sections.

## APPENDIX II

## AIRCRAFT CHARACTERISTICS

1. Detailed dimensions, weight and other characteristics of individual aircraft types do not normally influence design of airfields, which are broadly classified into five main groups :—

- (a) Emergency operational—below normal standard.
- (b) Fighter and light bomber—fully developed to full standards.
- (c) Medium and heavy bombers.
- (d) Transport.
- (e) Training (in non-operational areas).

Within each aircraft group provision is generally made for the most exacting type.

2. It often happens, however, that an existing airfield is needed to serve aircraft of a type not originally intended. The question of adaptability or extensions may then arise.

- (a) Weight of aircraft and tyre pressures influence surfacing and base course specifications.
- (b) Landing speed brings under review the length of runway and conspicuousness of markers.
- (c) Length and wheel span affects design of taxi-track and dispersal lanes and hard standings.
- (d) Wheel base dimensions affect layout of hardstandings and of curves on taxi-tracks.
- (e) Height of aircraft concerns hangar and pen accommodation.
- (f) Wing span affects hangar and pen accommodation and the width of the zone to be cleared on each side of taxi-tracks and landing strips.
- (g) Petrol storage capacities are related to the fuel consumption of individual aircraft.

3. Range of aircraft has a direct bearing upon location of sites in relation to probable targets or zones of defence. Long range will sometimes allow choice of sites to be more elastic, and a rear location to be acceptable on account of soil characteristics favouring rapid construction.

4. Aircraft without filters may have engine lives reduced to 100 hours or less by dust abrasion under certain conditions of soil and climate. Measures for alleviation, especially at revving-up points, become urgent.

5. Single engine fighters are badly adapted to long taxi-ing distances. They rapidly overheat.

6. Different angles of climb materially affect approach zone requirements, but this factor is essentially a direct air force responsibility.

Essential figures are given below for a typical selection of British and American aircraft.

# AIRCRAFT CHARACTERISTICS

Type and mark	Overall length ft.	Max. op. weight lb.	Tyre pressure lb.	Span width ft.	Height ft.	Wheel tracks ft. in.	Take-off in yds. over 50 ft. loaded	Landing in yds. over 50 ft. empty	Landing speed m.p.h.	Remarks
Spitfire VIII	30-0	7,846	57	40-2	10-0	5 8½	550	720	86	*15 degrees flap.
Spitfire XXI	30-7	8,000	60	40-2	10-0	5 8½	625	830	93	
Hurricane IIe	31-5	8,000	44	40-0	10-5	7 10	590	600	83	
Typhoon	32-0	13,500	45	41-5	15-0	13 7	740	870	94	
Lightning	37-5	20,000	44	52-0	10-0	16 6	580	800	90	
Mustang I	32-5	10,500	45	37-2	8-7	11 10	640*	880	90	
Thunderbolt	36-0	15,000	55	40-8	14-2	15 6	1,100	910	100	
Baltimore III	48-5	24,000	43	61-3	16-2	17 3	850	850	110	
Wellington X	60-8	34,500	44	86-0	18-8	19 8	1,300	800	70	
Mitchell II	54-1	32,320	54	67-5	15-8	19 4	1,000	850	115	
Marauder II	58-2	36,500	70	71-0	21-5	21 11	1,400	1,400	145	
Dakota ..	64-5	31,000	48	95-0	17-0	18 6	1,000	900	100	* Nose wheel 45 lb.
Lancaster IV	68-9	70,000	—	120-0	19-5	23 9	1,000	850	73	
Halifax II	70-1	60,000	64	98-0	20-7	24 8	1,200	850	73	
Sterling III	87-0	70,000	35	99-0	22-7	25 6	1,400	1,100	72	
Fortress II	73-9	59,000	75	103-9	19-3	21 2	1,400	1,150	95	
Liberator III	66-0	59,000	75*	110-0	18-0	25 8	1,600	1,100	105	

The above figures, given for general guidance only, are favourable, being based largely upon aircraft acceptance trials.

# NAVAL AIRCRAFT CHARACTERISTICS

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Type and mark	Overall length ft.	Max. op. weight lb.	Tyre pressure lb.	Span width ft.	Height ft.	Wheel tracks ft.	Take off yds.	Landing yds.	Landing speed m.p.h.	Remarks
Seafire Fighter...	30-0	7,414	57	35-8	10-0	5-8	350	600	85	
Corsair Fighter	33-3	13,795	90	40-7	15-4	12-1	600	700	75	
Swordfish Torpedo Bomber	35-8	9,115	45	45-5	12-0	10-5	600	630	65	
Firefly Fighter Bomber	37-0	12,115	40	44-5	12-4	11-8	465	745	87	
Firebrand Fighter Bomber	37-5	14,000	45	49-8	12-8	9-5	610	430	80	
Avenger Torpedo Bomber	40-0	16,250	80	54-2	12-4	10-8	620	700	82	

## ESSENTIAL FEATURES OF TWO FLYING BOATS

Type	Length ft.	Weight lb.	Span ft.	Height above water ft.	Draught ft.	Width of beaching classis ft.	Take off yds.
Catalina IV	65-1	34,500	100-0	16-1	3-4	12-5	2,250
Sunderland IV	88-3	73,100	112-8	28-7	4-8	13-4	1,900

The above figures, given for general guidance only, are favourable, being based largely upon aircraft acceptance trials.

**Wheel base**

A few typical wheel base dimensions are :—

			ft.	in.			ft.	in.
Hurricane II	...	...	19	5	Dakota D.C.3	...	38	0
Spitfire	...	...	21	3	Lightning (tricycle)	...	13	6
Baltimore	...	...	30	9	Marauder (tricycle)	...	14	6
Wellington	...	...	33	0	Mitchell (tricycle)	...	16	4
Halifax	...	...	43	4	Liberator (tricycle)	...	16	0

**Normal range of aircraft, without long-range tanks :—**

Single engine fighters	...	...	...	400–650 miles
Twin engine fighters	...	...	...	800–1,450 miles
Twin engine light bombers	...	...	...	950–1,500 miles
Twin engine, medium bombers	...	...	...	1,600 miles
Four-engine heavy bombers	...	...	...	1,800–2,800 miles

Fuel consumption, governing scales of petrol storage, is roughly five miles to the gallon for single engine fighter, 3 m.p.g. for twin-engine fighters, 2 m.p.g. for twin-engine medium bombers, and 1 m.p.g. for heavy bombers.

## APPENDIX III

## AERONAUTICAL NOTES

**Selection of airfields from air force standpoint**

1. The layout of airfields has been considerably affected by the advance in aircraft design and increasing aircraft weight. The manoeuvrability in the air affects approaches and circuits, while on the ground it affects gradients and radius of turns. Increased weight necessitates strengthened tracks and hardstandings to prevent aircraft sinking into the ground. Nature of soil is important and good drainage is essential. Operational efficiency requires quick access to take-off points, quick clearing of the runways after landing and quick refuelling arrangements.

2. A considerable area of ground, apart from the landing strips, is required. A site that gives, perhaps, good landing strips along narrow ridges but has no area for taxi-ing and dispersal is therefore useless. There is great variation in the absolute minimum requirements necessary for types, varying in flying capabilities and weight.

3. The following notes bring out some of the major points necessary for operational efficiency and safety. They should always be kept in mind as an ideal to be aimed at, though military considerations in the field will in many cases necessitate a considerable modification. If, however, the modifications are too drastic, the crash rate will become too high to be acceptable. To effect the best compromise requires accurate and skilled judgment.

**The flying aspect**

4. An understanding of the pilot's difficulties will greatly assist in the selection of a suitable airfield site. There is a vast difference between an untired pilot landing directly into wind on a clear day, and a pilot returning tired from operations in fog or at night, making a cross-wind landing on a narrow strip. Fatigue is apt to affect the pilot's judgment and so every effort must be made to make the process of landing as easy as possible for him. Bad visibility may be due to low cloud, haze, ground mist, snow, heavy rain or darkness. On the ground visibility may appear reasonable if one can distinguish a tree at, say, 200 yards; but for an aircraft to cover that distance would mean only three seconds for the pilot flying at a normal speed of circling (150 m.p.h.). Wireless aids may be used but they require better approach conditions than for ordinary landings.

5. When an aircraft is approaching an airfield, the pilot first makes a left-hand circuit at a height of about 1,000 to 1,500 feet. The left-hand circuit is standard for all types because in the heavy types the pilot's seat is rather on the portside and he cannot get a good view to starboard. The height of circuit is governed by the height of the cloud base and also, perhaps, by the proximity of other airfields when circuit heights are pre-arranged to avoid collision between aircraft circling different airfields. The height of circuit in good visibility is normally about 1,500 feet, but in bad visibility it may be just above ground level. The presence of hills and high obstructions, such as chimneys, church towers and W.T. masts is an important matter.

6. The radius of circuit depends on the type of aircraft. It may be as little as two miles in the case of a fighter, or as much as five miles or more for a heavy bomber, such as a Liberator. Hills in the vicinity should be avoided, as an aircraft coming down through cloud may not know just where it can "break cloud" and it might fly into a hillside on the way down, particularly, as sometimes happens, if the radio gear is shot away. The pilot asks by radio for permission to land; normally an aircraft no more comes in to land without permission than does a train come into a station.

7. On receiving permission, the pilot gets into position in the approach funnel at the leeward end of the landing strip. He must land into wind to have as low a ground speed as possible. To explain this: The pilot approaches at about 115-150 m.p.h. to allow a margin for full control of his aircraft, though he actually touches down according to the type of aircraft at between 80-140 m.p.h. The air speed is the speed of the aircraft through the air, and the ground speed is that over the ground; so that if a pilot is landing at 80 m.p.h. into a 20 m.p.h. wind, he touches down at  $80 - 20 = 60$  m.p.h., while if he lands down-wind he touches down at  $80 + 20 = 100$  m.p.h. An aircraft running along the ground at excessive speed is apt to become more unmanageable than a car in similar circumstances. For this reason, a pilot must land as nearly into wind as possible, as well as for the reason of avoiding collision with aircraft landing in the opposite direction.

8. Having got into position in the landing funnel the pilot partially throttles back the motors, lowers the wheels and flaps and rumbles in at a flat approach angle. If the landing runway is short, he endeavours to touch down at the beginning of it. Any obstacles to a flat approach make him land further along the runway and so lose the benefit of the full length. If the landing is across wind, the aircraft tends to swing to one side or the other, dependent on a number of factors. If the runway has a cross slope on it, most aircraft tend to swing downhill. There is but little difference in the technique of landing a tricycle undercarriage aircraft. The surface of the ground must be as level as possible to lessen bumps, and thus reduce maintenance of undercarriages. Aircraft brakes on the ground are effective for a short time, but brake pressure soon goes. In any case, heavy braking is hard on the airfield surface.

9. The trend of modern aircraft design, especially with aircraft of the taper-wing type, in certain cases has altered landing technique, and has created the practice of flying in rather than gliding-in, of wheel landings at higher speed rather than three-point landings at slow speed, and "throttle landings" rather than "stick landings." This practice ensures the effective control of the aircraft and eliminates the possibility of turbulence or eddies arising near the surface from upsetting its equilibrium until its weight is adequately supported by the ground. This practice necessitates a lower approach angle and a longer distance of approach than would otherwise be necessary with the practice of "three-point landings."

#### On the ground

10. A pilot must get clear of a runway as soon as possible. Left-hand circuits on the ground are again the rule, both for one-way traffic reasons, and also so that the pilot behind the leader knows which way

the leading aircraft is going to turn after landing. This is very important in the case of a fast landing, when a succeeding pilot might have to take off again.

11. Taxi-tracks are difficult for a pilot to see in the dark and so should be as straight as possible, otherwise at a turn a wheel may get bogged on the side of a track and all traffic held up. It is realized that straight tracks are bad from a camouflage point of view, but this has to be accepted. Turns when taxi-ing mean braking and that uses up brake pressure. An aircraft may well use up all its brake pressure in taxi-ing halfway round a perimeter track with many turns in it, after which the brakes become useless. The radius of turn is important, both from the brake pressure point of view and the wear and tear on the track. Quick turns mean locking one wheel, which increases loads on the ground and often breaks up even tarmac or concrete surfaces. Straight lengths of taxi-track with a few sharp turns are preferable to long continuous, if easy, curves which necessitate constant braking.

12. Hardstandings should not be in a straight line, otherwise hostile aircraft can fly along the line shooting up all aircraft at one time.

13. The pilot on landing must report at once to the Report Centre; the aircraft must be checked over and refuelled. The task of getting petrol to hardstandings must be provided for. If lorries use the track, the latter will become unusable for aircraft. The pilot cannot leave his aircraft at a special refuelling point while he reports, as that prevents an even flow of traffic.

## APPENDIX IV

## LABORATORY SOIL TESTS

## Moisture content determination

Moisture contents of natural and compacted sub-grade, compacted fill, and base-course material should be determined for the purpose of design, and for control of compaction during construction. Moisture content determination is also required for the California bearing ratio, expansion, density, compaction, liquid limit and plastic limit tests.

Moisture content is expressed in percentage of dry weight of the soil, obtained by placing a relative specimen of the wet soil in a metal container and thoroughly drying the specimen in an oven. If the soil is free from organic and other combustible matter, the sample may be dried over a fire. The wet weight of the specimen before heating, and the dry weight having been determined, the moisture content may be computed from the following formula:—

$$P = \frac{W_w - W_d}{W_d} 100 \text{ per cent.}$$

where  $P$  = Moisture content as a percentage of dry weight.  
 $W_w$  = Weight of wet sample.  
 $W_d$  = Weight of dry sample.

## Liquid limit—LL test

Liquid limit is the moisture content expressed as a percentage by weight of oven-dry soil, at which a remoulded soil will begin to flow when jarred slightly. Liquid limit in conjunction with plastic limit is of great value in proper identification and classification of fine-graded soils in a remoulded state.

The equipment used consists of a mechanism for producing uniform blows on the bottom of a dish. The test should be carried out using a representative sample of the fraction of soil passing the No. 40 American sieve. 50–80 grammes of the sample are thoroughly mixed with water to form a heavy paste and placed in a dish. The soil is grooved with a special tool, which is drawn through the soil specimen along the diameter of the cup passing through the centre of the hinge.

In cutting, the groove of the tool should be perpendicular to the surface of the dish. Shoulders of the tool should remove soil for a length of about  $1\frac{1}{2}$  inches when the dish is properly filled. In clay soils, one stroke of the tool will normally make a clean groove. In silty soils, several strokes of the tool, or a spatula, using the tool to check the dimensions, may be necessary.

After the soil is placed in the dish and the groove properly formed the crank of the liquid limit mechanism is turned approximately two revolutions per second. The number of shocks required to close the bottom of the groove for a distance of  $\frac{1}{2}$  inch is determined. Part of the specimen is placed in a metal container and the moisture content determined as already described. The above procedure is repeated at various moisture contents and a graph plotted showing the relation between moisture content and the number of shocks required. The water content corresponding to 25 shocks, obtained from the graph is defined as the liquid limit.

### Plastic limit—PL test

Plastic limit is the lowest moisture content expressed as a percentage of the dry weight at which soil can be rolled into threads of  $\frac{1}{8}$  inch diameter without crumbling. Plastic limit is the moisture content at which cohesive soils pass from a semi-solid to the plastic state. Thus, if natural moisture content of soil is less than the plastic limit, the soil possesses relatively high stability.

The test is performed on a representative sample of the soil fraction passing the No. 40 American sieve. A sample of the soil is mixed thoroughly with water to form a plastic mass at a moisture content somewhat above the plastic limit. A specimen about  $\frac{1}{2}$ -inch cube is removed from the plastic sample and rolled on a flat non-absorbent surface with the palm of the hand, forming a roll about  $\frac{1}{8}$  inch diameter. If crumbling does not occur at that moisture content, fold, knead, and re-roll as before. Repeat this process until the water content is reduced to the plastic limit, which is reached when crumbling occurs as soil is rolled out to a diameter of about  $\frac{1}{8}$  inch. Moisture content of the sample is determined.

Some soils cannot be rolled into threads at any moisture content, and consequently do not have a plastic limit. Test results are then reported as non-plastic (N.P.).

### Plasticity index (P.I.)

This index is the difference between liquid limit and plastic limit. It is determined by taking the numerical difference between the two values: for example, if the liquid and plastic limits of a soil are 28 and 24 respectively, the plasticity index is 4.

A cohesive soil with a low plasticity index has better stability than one with a high value. Non-plastic soils are considered to have a plasticity index of zero.

(The above notes have been extracted from the American Manual "Aviation Engineers," TM5-255.)

## APPENDIX V

### LABORATORY COMPACTION AND OPTIMUM MOISTURE TEST

The following notes describing the modified test procedure adopted by the American Association of State Highways Officials, are extracted from the American Manual "Aviation Engineers," TM5-255.

The density to which a soil may be compacted with a given compaction effort depends upon the moisture content. Moisture content at which the greatest density is obtained with a given compaction effort is termed optimum moisture. Optimum moisture is not a constant for a given soil, but is variable, depending upon the amount of compaction effort. It decreases with an increase of compaction effort, and in general is such that the air content of the soil (unfilled voids) is from 2-8 per cent. by volume, depending upon the characteristics of the soil.

In runway pavement construction it is desirable to compact sub-grade fill, upper zones of sub-grade cuts, except in clay soils, and base course materials, to as great a density as is practicable in order to obtain greatest stability and prevent detrimental settlements. It has been found that the maximum density which can be obtained in actual construction, using ordinary heavy compaction equipment, is duplicated closely in the laboratory by the Modified A.A.S.H.O. test procedure.

Special equipment required to make the test consists of a Proctor cylinder, and a metal tamper with a striking face 2 inches in diameter weighing 10 lb. The Proctor compaction cylinder is a metal cylinder, having an internal diameter of 4 inches and a height of 4.59 inches. Its volume is  $1/30$  of a cubic foot. The cylinder has a removable base plate, and a removable extension of the cylinder of the same internal diameter and approximately  $2\frac{1}{2}$  inches in height.

Test procedure is as follows :—

1. Air-dry a sample weighing approximately 6 lb. and remove all material not passing the  $\frac{1}{4}$ -inch sieve.
2. Determine and record tare weight to 0.05 lb. of the Proctor cylinder with attached baseplate but without the extension.
3. Thoroughly mix the sample with a sufficient quantity of water to obtain a damp mixture, taking care not to add too much water.
4. With the extension attached, fill the Proctor cylinder in five layers, compacting each layer to approximately 1 inch thickness by dropping the tamper 25 times. The height of drop should be 18 inches above the soil and blows should be distributed over the soil layer surface. When using this compaction equipment for density and control tests for soil cement construction the height of fall of the tamper should be restricted to 6.5 inches to get good results.
5. Carefully remove the extension piece and level off the top of the soil with a straight edge.
6. Determine the unit wet weight ( $U_w$ ) of the compacted soil in lb./cubic feet.
7. Remove the soil from the cylinder, extract from the centre a sample weighing about 100 grams and determine its moisture content ( $P$ ).

8. Compute the unit dry weight ( $U_d$ ) of the compacted soil using the data above.

$$U_d = \frac{100 U_w}{100 + P} \text{ lb./cu. ft.}$$

9. Thoroughly remix the remainder of the sample, adding sufficient water to increase the water content from 1-2 per cent. and repeat the process already described.

10. Repeat the procedure until points beyond the maximum density have been obtained.

11. From the density thus obtained prepare a curve showing the relation between moisture content and unit weights, dry and wet (unit weight as ordinate). The peak of the curve defines the optimum moisture and maximum density ( $\text{max. } U_d$ ) that should be used for compaction control during construction.

If the soil is uniform fine-sand, difficulties may be encountered when using the above procedure. Soil must contain sufficient binder, or be sufficiently well graded, to prevent upheaval during the use of the tamper. Otherwise initial stability should be produced by lighter blows before the standard blows are applied.

Only material passing the  $\frac{1}{4}$ -inch sieve is used in the test, and in consequence optimum moisture and dry weight obtained from the test are not representative of the total material if it contains any considerable amount of gravel particles. For control during construction it is necessary to determine unit weight and moisture-content only of material passing  $\frac{1}{4}$ -inch sieve. Stones greater than  $\frac{1}{4}$  inch should be removed from specimens used for moisture-content determinations. Unit weight can be determined by adjusting the unit weight of the total sample according to percentage by weight and volume of particles greater than  $\frac{1}{4}$  inch diameter in the soil. For predominantly gravelly soils this correction is not reliably accurate.

## APPENDIX VI

### CALIFORNIA BEARING RATIO AND EXPANSION TEST

Developed by the California Division of Highways, this test is used to determine the bearing characteristics of soils and base materials. Bearing ratio, is the load intensity required to produce 0.1 inch penetration of a piston 1.954 inches in diameter, *i.e.* 3 square inches, into a soil divided by the load intensity required to push the same piston 0.1 inch into a standard sample of compacted crushed stone. The samples usually are saturated before the penetration test. Bearing ratio is expressed as a percentage. For designing thickness of various base courses, bearing ratio should be determined for all sub-grade soils and base-course materials. Soils should be tested at a density comparable to that obtained in construction. Where moisture conditions are favourable and the airfield sub-grade will not accumulate moisture approaching a saturated condition, samples should be tested at a moisture content approximating true conditions during the time the airfield is used. In all other cases, samples are tested in a saturated condition.

The equipment consists of a metal cylinder 6 inches in diameter; buckets in which the soil sample is saturated; a loading device to force the piston into the soil, and attachments.

The test is carried out on samples compacted to the same degree as the material used in construction. The samples are taken from materials intended for use, except that any particles of material retained on the  $\frac{3}{4}$ -inch sieve are removed from the sample and replaced by an equal proportion of material passing the  $\frac{3}{4}$  inch, but retained on the No. 4 American sieve. Tests on blended materials are carried out with specimens containing the same percentage of mineral aggregate and binder material as those specified. Compaction tests with various numbers of blows are conducted to determine the optimum moisture content and the number of blows required, and the results recorded.

The sample is brought to optimum moisture and then compacted in a cylindrical mould 6 inches in diameter, under a load of 2,000 lb. per square inch. A duplicate specimen prepared in the same way is soaked in water for four days before testing. Samples, when compacted, should be 5 inches high and 6 inches diameter.

A piston 1.954 inches diameter, having a bearing area of 3 square inches is seated with an initial 10-lb. load on each specimen. This represents zero load when determining stress strain relations. Pressure is applied to the piston so that the rate of penetration is 0.05 inch per minute. Load readings at 0.025; 0.05; 0.075; 0.1; and then in increments of 0.1 to a penetration of 0.5 inch, are taken.

The loads of each increment of penetration of both samples are expressed in percentages of the standard loads (called bearing ratio) shown in the following table:—

<i>Penetration inches</i>	<i>Standard loads for crushed stone lb./sq. in.</i>
0.1	1,000
0.2	1,500
0.3	1,900
0.4	2,300
0.5	2,600

To obtain true penetration loads from the test data the stress deformation curve should be drawn, and the zero point adjusted to

eliminate the effect of surface irregularities. The value of C.B.R. per cent. is computed by using the following table :—

$$\text{C.B.R.} = 100 \frac{L_t}{L_c} \text{ (in per cent.)}$$

where C.B.R. = Value of C.B.R. in per cent.

$L_t$  = Test load in pounds to produce 0.01 inches penetration (from adjusted curve).

$L_c$  = Value from table above of standard load in pounds at 0.01 inch penetration.

The expansion test is made during the soaking period. The sample after being compacted is confined within the mould by a porous disc, and a 10-lb. weight, representing the surcharge effect upon the subgrade of 4-5 inches thickness of pavement. After the sample has soaked for four days the swell is recorded. The expansion of the sample during the test is reported as a percentage of the volume of the compacted sample before soaking.

(The above notes have been extracted from the American Manual "Aviation Engineers" TM5-255.)



To fac

Major

COARSE GRAINED SOILS.

FINE GRAINED SOILS  
Containing little or no coarse grained  
material

Fibro  
with  
press



## APPENDIX VIII

## METHODS OF CALCULATING THE CAPACITY OF DRAINAGE SYSTEMS FOR AIRFIELDS

The following notes are extracted from reports of the Road Research Laboratory, Harmondsworth, and the American Manual "Aviation Engineers," TM5-255.

The channels of any drainage system should be of adequate capacity without uneconomical results of over designing. In the British Isles empirical methods based on previous experience have been used for computing the capacities of drainage systems. The modern practice is to adopt methods of design based on rational principles, which can be universally applied to drainage areas of all kinds.

Computation of storm drainage capacity may be divided firstly into the calculation of maximum rate of flow at various points in the system, and secondly, the determination of the size of drain required to carry this rate of flow. The run-off of surface water is controlled by the dimensions and characteristics of the watershed, the maximum rainfall intensity on which the design is to be based, and the time concentration for the watershed, being the time taken for the water to travel from the most distant part of the area to reach the drain entrance.

**Surface run-off** may be estimated by the formula :—

$$Q = A.I.R.$$

where  $Q$  = rate of run-off in cu. ft./sec.

$A$  = area of watershed in acres.

$I$  = percentage imperviousness of watershed.

$R$  = maximum average rainfall intensity during the time of concentration inches/hour.

The value of  $I$  may be determined from the following table :—

Type of surface	Percentage of imperviousness
Paved areas on airfields	85-95
Impervious soil with turf	40-70
Impervious soil without turf	50-80
Pervious soil with turf	10-30
Pervious soil without turf	20-50

**French drains used to collect surface water.**—The formula is :—

$$Q = \frac{A.I.R.}{T+t}$$

Where  $Q, A, I$  have the same values as previously.

$R$  = one hour rainfall in inches, having chosen frequency of occurrence.

$T$  = duration of rainfall in hours.

$t$  = time allowed for removal of the rainwater after the storm.

$T$  is normally taken as 1 hour, and  $t$  as two hours. Sometimes allowance is made for surface slope, in which case the factor  $f$  is substituted for  $(T+t)$ . Suggested values for  $f$  being :—

Average slopes of 0.05 per cent. or less	...	...	3
Average slopes of 0.05—1 per cent.	...	...	2.5
Average slopes of more than 1 per cent.	...	...	2

**Rate of sub-surface run-off** using an independent main drain :—

$$Q = AZ.$$

where  $Q$  = discharge in cu. ft./sec.

$A$  = area to be drained in acres.

$Z$  = rate of sub-surface run-off in cu-ft./sec., recommended values for  $Z$  are :—

*Annual Precipitation  
(inches)*

30 or less

30-40

40-50

50 or more

*Rate of sub-surface run-off  
cu. ft./sec./acre*

0.0105

0.0147

0.0210

0.0315

The following formula may be used for estimating the capacity of pipes and open channels.

$$Q = A \frac{1.486}{n} r^{\frac{2}{3}} S^{\frac{1}{2}}$$

### **Pipes and open channels**

where  $Q$  = quantity of water drain will carry in cu. ft./sec.

$A$  = cross-sectional area of drain in sq. ft.

$r$  = mean hydraulic radius of pipe in feet.

$S$  = hydraulic gradient in feet per foot of pipe.

$n$  = co-efficient of roughness :—

= for concrete pipes 0.015.

for earth channels 0.025.

for sodded channels 0.030.

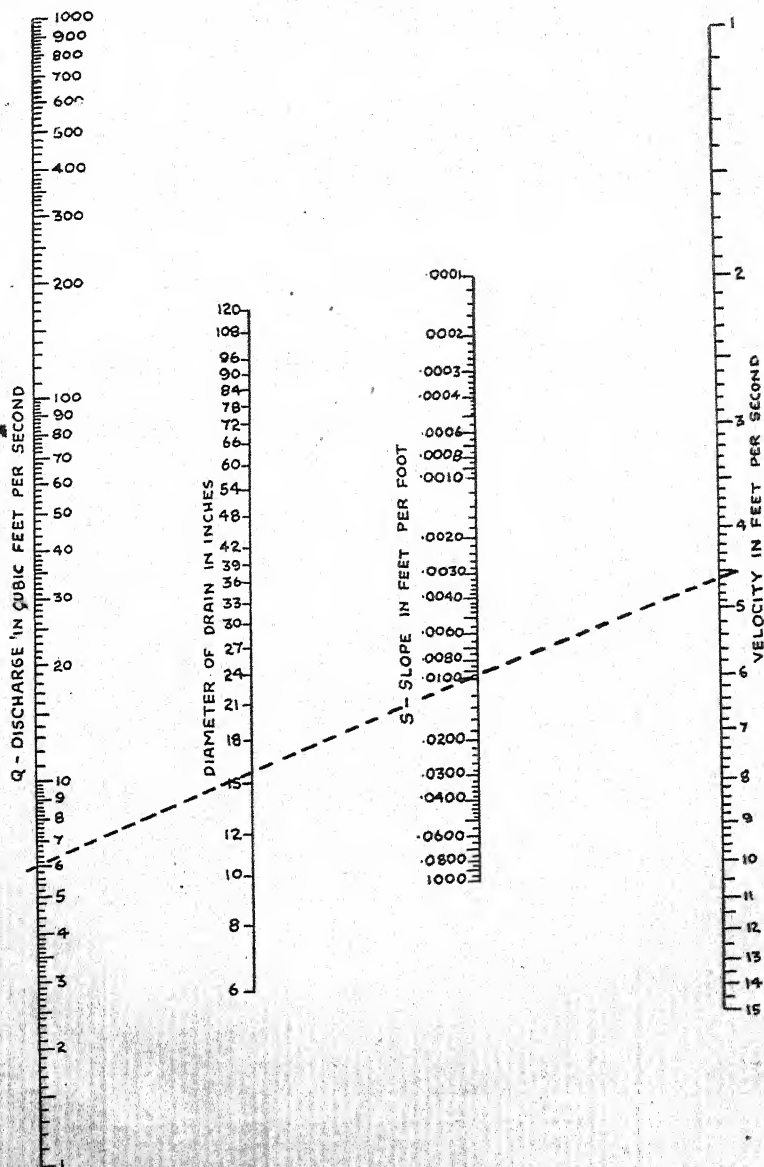


PLATE 94.—

GRAPHICAL SOLUTION OF  $Q = A \frac{1.486}{n} r^{\frac{2}{3}} S^{\frac{1}{2}}$  FOR CIRCULAR  
PIPES (BASED ON MANNING'S FORMULA FOR  $n=0.015$ )

## APPENDIX IX

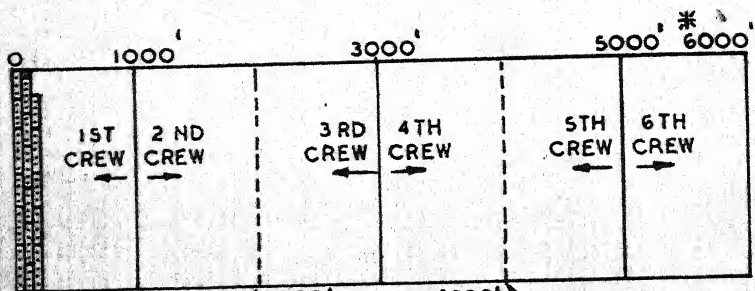
## PIERCED STEEL PLANK LAID IN MULTIPLE FACES

A method of laying pierced steel plank from six faces simultaneously was introduced by American aviation engineers in Italy. By this means the speed with which the mat can be laid is tripled, provided that adequate services are available.

A test was first made after half a runway mat had been laid in the normal way. Two laying parties began laying the mat at a point half-way from the unfinished end of the runway. It was calculated that the mat would meet with no more than a  $7\frac{1}{2}$ -inch gap or overlay. With  $\frac{1}{8}$ -inch slack at each joint the possibility of making the mats join seemed feasible.

When the two faces met at the middle of the runway, there was a gap of 7 inches on one side of the runway, while on the other the gap was negligible. Along the sides the faces were about 3 inches out of alignment. This was corrected in one operation by a pull from a heavy tractor. The 7-inch gap was closed in two operations, consisting of one pull on each face, by tractor, in a direction parallel to the runway. The tractor was attached to the mat by means of a double chain through two of the holes in a section of the plank nearest the outer edge, and about 10 feet from the connecting edge of the face. Five men and a tractor made this connection in less than an hour. Had the mat overlapped the edges of both faces were to be raised while the last planks were inserted and clipped. The mat would then be pulled from a point 20 to 75 feet from the connection of the faces, and sufficiently contracted to take up the excess.

Great care must be exercised in making the starting lines parallel, and the face constantly checked with the starting line. If one side runs ahead, straighten by pulling that side back towards the starting point, rather than stretching the receding side. Thus all slack available is left in the runway for final adjustment of the joints.



STARTING POINTS  
ARE AT THE 1000  
3000 & 5000 FT  
MARKS.

THE THREE SEGMENTS OF  
THE RUNWAY ARE  
CONNECTED AT THESE  
TWO POINTS.

\* 6000' LENGTH  
SHOWN FOR  
EXAMPLE ONLY.

PLATE 95.—SIX-FACE LAYING SCHEME FOR P.S.P. RUNWAY

## APPENDIX No. X DUST ALLEVIATION

Surface treatment to reduce the menace of dust, as opposed to methods of maintaining stability in wet weather, is a frequent and critical demand upon operational airfields. Practice ranges from compaction with oil or water, to the construction of some thin form of paving. The use of bituminized hessian, alone amongst prefabricated portable mats, serves the dual purpose of checking both dust and deterioration by rain.

It is axiomatic that all vegetable growths and natural surfaces should be maintained as intact as possible around runways and taxi-tracks. In dry windy weather, dust storms commonly arise from activity outside areas used by aircraft.

Perimeter traffic control is also essential to reduce to a minimum the incidence of dust, which affects so seriously the factors of visibility and engine life.

Material	Method of application	Amount required	Results
Pre-fabricated bituminized hessian.	Laid as a surface course.	1,150 rolls per runway of 1,000 $\times$ 50 yds.	Excellent.
Asphalt impregnated fabric (U.S.A.).	Cotton "Osnaburg" cloth tacked down to surface with 4-in. wire staples. Treated with cutback asphalt M.C. 2 at 150°-175° F.	$\frac{1}{2}$ gal. asphalt per sq. yd.	Good results. Used under prefabricated steel mats.
Straw reeds or other suitable fibrous material.	Spread evenly over surface and anchored to soil by running over with disc harrows.	1.25-1.5 lb./sq. yd.	Good dust palliative under steel mat runways.
Oil.	Heavy fuel oils with small, wax content, 3-5 applications. Light oils—dressings 2-4 weeks—and after heavy rain.	0.7-0.25 gal./sq. yd. 0.25 gal./sq. yd.	Good results in Middle East on loam and well graded soil.
Salt and brine.	Calcium and magnesium chloride flakes spread over surface.	3 lb./sq. yd.	Satisfactory on suitable soils under favourable climatic conditions. Rarely justified under operational conditions.
	Brine sprayed over a pulverized surface and compacted.	2 gals./sq. yd. 3 dressings (minimum).	Very successful on fine clayey sand. Corrosive effect on equipment.
Vinsol resin.	Mixed with pulverized soil and a solution of caustic soda and water (17 lb. soda-100 lb. resin). Compacted with pneumatic rollers.	1.5 lb./sq. yd.	Satisfactory tests on sandy-clay soils.

Material	Method of application	Amount required	Results
321 resin.	Applied to stabilized soil surfaces.	1 lb./sq. yd.	Satisfactory. Suitable only for acid soils.
Sodium rosinate with aluminium sulphate.	Solution 1 part sodium rosinate, 2 parts water sprayed over surface.	2½ lb./sq. yd.	Surface improved though doubtful whether it would withstand heavy use after rain. Unsuitable for soil of high clay or silt content.
Sodium silicate.	Sprayed over surface.	0.25-0.7 gal./sq. yd.	Very poor results — material hardens when dehydration takes place, but does not bond. After rain material flakes and swells badly.
Live turf.	Scarred or barren areas may be covered with new growth. Quickly germinating seeds or sprigs of native grasses should be used where possible.		Suitable only when soil and climate are favourable.
Cutback asphalt.	Evenly distributed and allowed to penetrate.	0.6 gal./sq. yd.	Satisfactory in semi-arid and humid regions, with soils of suitable type.
Emulsified bitumen.	Mixture of 1 part emulsion—2 parts water sprayed on surface. 4-5 applications.	½ gal./sq. yd.	Forming a surface skin of asphalt, on which steel mats can be laid.
Untreated pit-run gravel.	2-in. layer, well compacted.		For standings and aprons.
Treated pit-run gravel.	2-in. layer, treated with wood lignin or liquid asphalt.		Inexpensive and should withstand propeller blast.
Plant mix.	Hot or cold liquid asphalt mixed with suitable soil and compacted.	1-in. thickness.	Satisfactory.

Choice of method is governed by climate, type of soil, and material resources available.

## APPENDIX XI

## METHODS OF CALCULATING PERFORMANCE OF MECHANICAL EQUIPMENT

1. **Bulldozer and Angledozer.**—Short haul excavation, stripping, backfilling and building stock piles.

$$\frac{Q \times f \times 60 \times E}{Cm} = \text{cu. yds. per hour.}$$

Where Q = Bowl capacity.

• Typical values of Q in loose measure are :—

D8—3.88 cu. yds.

D7—3.38 cu. yds.

D4—2.38 cu. yds.

f=conversion factor from loose yards to excavated yards.

The following values may be used :—

Rock 0.05.

Common earth 0.8.

Wet bulky clay 0.7.

Sand 0.9.

E=Percentage efficiency, i.e., estimated total work per hour having regard for operator's ability, condition of material, weather conditions, etc.

Cm=Cycle time in minutes calculated as follows :—

(a) Travel speed forward, based on average speed of 1.5 m.p.h.

(b) Changing gear—approx. 0.16 minutes.

(c) Travel speed backwards—usually 2.5 m.p.h.—  
D.7 has higher reverse speed of 5 m.p.h.

(d) Changing gear preparatory to next cycle approx. 0.16 mins.

2. **Scraper**—the standard formula for tractors applies :—

$$\frac{Q \times f \times 60 \times E}{Cm}$$

Where Q = Scraper bowl capacity (loose yards).

f=Conversion factor to excavated or compacted yards.

E=Percentage efficiency (estimated total work per hour).

Cm=Cycle time in minutes.

=Total fixed plus total travel time.

## TOTAL FIXED TIME IN MINUTES

Task	Scraper (loose capacity)	
	15 cu. yds.	11 cu. yds.
Loading ... ..	1.50	1.00
Spreading ... ..	0.50	0.50
Turning ... ..	0.50	0.50
Gear changes ... ..	0.50	0.50
Total ... ..	3.00	2.5

Total travel time = hauling and return distance at 4 m.p.h.

3. Tournapull performance is calculated from the standard formula

$$\frac{Q \times f \times 60 \times E}{C_m}$$

Where Q = Scraper capacity (15 loose yds.).

f = conversion factor as for tractors.

E = efficiency (normally 75 per cent. under average conditions).

C<sub>m</sub> = Fixed time plus Variable time.

Fixed Time=Loading with pusher	...	...	...	1.0 min.
Spreading	...	...	...	0.5 min.
Turns at each end	...	...	...	0.5 min.
Gear change and acceleration	...	...	...	1.0 min.
Total fixed time	...	...	...	3.0 min.

Variable time = Haul speeds affected by :—

- (a) rolling resistance (condition of road).
- (b) Grades (adverse and favourable).
- (c) Load (gross).

When determining the travel cycle time it will be necessary to refer to the various speeds and pulling power (rimpull) of the Tournapull.

1st Gear—2.7 m.p.h.—16,698

2nd Gear—4.6 m.p.h.—9,843

3rd Gear—8.5 m.p.h.—5,295

4th Gear—14.9 m.p.h.—3,008

Additional power for loading is obtained by a "pusher" tractor.

*Pusher formula.*—To determine the number of scrapers a pusher will serve, apply the following formula :—

$$\frac{\text{Complete cycle time of the scraper in minutes}}{\text{Cycle time of the "pusher" in minutes.}}$$

Cycle time of pusher to load one unit is averaged at 1.5 to 2 minutes, depending upon material, condition of surface, etc.

It is not practical to operate more than about four scrapers to one pusher owing to the difficulty of keeping all of them properly spaced.

4. **Sheepsfoot rollers.**—Performance calculations are seldom required for compaction work. Occasionally, when large fleets of scrapers are working it may be necessary to calculate the number of rollers required to compact the volume of material spread.

*Production formula*

$$\left. \begin{array}{l} \text{Loose cubic} \\ \text{yards per hour} \end{array} \right\} = E \times 60 \times \frac{\text{speed of travel}}{\text{ft./min. at 2.5 m.p.h.}} \times \frac{\text{effective drum width}}{\text{in ft.}} \times \frac{\text{loose layer depth}}{\text{in ft.}}$$

No. of passes  $\times 27$ .

For excavated or compacted yards multiply by the factor (f).

(These notes have been extracted from American Manual TM5-9500, "Principles of Modern Excavation and Equipment" and "Airport Construction," prepared by Le Tourneau Company.)

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